Explanation #1

(STD > 1.5) (Idso < 0.16, SDD < -2.4)

The temperature variability is greater than normal. This ~~result~~ may be caused by two factors:

1) erroneous data -- ~~non crop temperatures were inadv~~ (such as soil temperatures) were included in the data.

2) there are a few relatively hot areas present in the field. The vast majority of the field does not need water, but these few areas do. Since many farmers irrigate for the field as a whole, we recommend not irrigating. However, this can be considered an "early-warning" of moisture stress and you may decide whether or not to irrigate.

Explanation #2

This program contains error checking routines. If the recorded temperature is ~~more~~ more than 14°F below ~~ambient air temperature~~ or ~~more~~ more than 14°F above air temperature the data is automatically excluded from the calculations.

#3

°C - IRT Temperature Stored in Register 2

°F - displayed externally

°C - Air Temperature Stored in Register 7 (Dry bulb)

Σx - Stored in Register 1

~~$(\Sigma x)^2$ Stored in Register 2~~

°C - wet bulb in Register 8

W/m^2 - Radiation in Register 9

m/sec - windspeed in Register 10

N - Number IRT observations in Register 3

(Σx^2) - in Register 4

$\bar{x}$ - in Register 5

Std - in Register 6

Hour/Minute - Register 12

Month/Day - Register 13

(Crop - Air) Temperature Register 11

Monthly

1) Happening

- Activities
- work Hours
- Status

72.264
72.229
72.191
74.103
73.565

72.953
72.934
73.148
73.791
73.585

22.935 = 73.283

0.430 (0,387)

DATA Storage FORMATS Registers

Month/Day	A4	12
Hour/min	A4	13
~~wet~~ wet bulb	N4.1	8
Dry bulb	N4.1	7
Solar Radiation	N4.1	~~14~~ 9
Windspeed	N2.0	~~15~~ 10
Mean Dry side IRT	N4.1	16
Std. Dryside IRT	N3.1	17
Mean Wet side IRT	N4.1	18
std. Dry side IRT	N3.1	19
Location	A16	5

#4

Register Assignments

Form Reg #	
0	analogy IRT data (V) (mV) Radiation sensor (mV)
1	Σ IRT °C
2	°C IRT
3	N = number of IRT measurements (becomes N-1) when program is exited
4	$[\Sigma(IRT)^2]$ °C^2
5	$\overline{IRT}$ mean IRT value
6	Std °C - Standard deviation
7	Dry bulb Air Temp °C
8	wet bulb Air Temp °C
9	Radiation W/m^2
10	Windspeed m/sec
11	Crop-Air Temperature °C
12	Hour/minute
13	month/day
S	Location
14	Mean Dry Side IRT °C
15	Std. Dry side IRT
16	Mean Wet Side IRT °C
17	Std. Wet side IRT

Everest CWSI Program 5/28/86

^ = & = ampersand
B = Blank

*Note: all Y/N must be CAPITAL Letters
small Letters are ignored.

```
10: TROFF : T3$ = "^^^^^^^^^^^^^^^^^^^^"
20: YN$ = "1" : SC$ = "" : Wait 2 : PRINT USING T3$; "BBBBBBBBBBBBBBB"
30: Wait : Restore : INPUT "USE Table? Y/N "; YN$
40: IF YN$ <> "Y" THEN GOTO 460
50: INPUT "INPUT Crop Name"; SC$
60: READ S1$, S2$, S3$, S, I
70: IF (S1$ <> SC$) AND (S3$ <> "") THEN GOTO 60
80: IF S3$ <> "" THEN GOTO 100
90: PRINT "CROP NOT FOUND" : GOTO 30
100: IF (S2$ = "") OR (S2$ = "NO-tassels") THEN GOTO 240
120: SP$ = LEFT$(S2$, 3): IF YN$ = "Y" THEN GOTO 150
130: IF SP$ = "POS" THEN GOTO 210
140: SP$ = "pos" : GOTO 170
150: IF SP$ = "pre" THEN GOTO 220
160: SP$ = "pre" : GOTO 170
170: READ S1$, S2$, S3$, S, I
180: IF ((S1$ <> SC$) OR ((LEFT$(S2$, 3)) <> SP$)) AND
     (S3$ <> "") THEN GOTO 170
190: IF S3 = "" THEN GOTO 20
200: IF S3 = "PRE" THEN GOTO 220
210: Wait 50: PRINT "USING post-heading" : GOTO 230
220: Wait 50: PRINT "USING pre-heading"
230: PRINT "  #  ", "VALUES"
240: READ T1$, T2$, T3$, TA, TC
250: IF ((S1$ <> T1$) OR ((LEFT$(T2$, 3)) <> SP$)) AND
     (T3$ <> "") THEN GOTO 240
```

(NEEDS $) ERROR (NEEDS $) ERROR

```
260: IF (T3$<>"") Then GoTo 270
265: YN$ = "1": GoTo 450
270: Wait 35
280: PRINT "Now Select"
290: PRINT "", "Species"
300: Wait 60
310 PRINT S3$
320: INPUT "(Y/N)? "; YN$
330: IF YN$ = "Y" Then GoTo 450
340: S3$ = T3$: S = TA: I = TC
350: PRINT S3$
360: INPUT "(Y/N) "; YN$
370: IF YN$ = "Y" Then GoTo 450
380: Read S1$, S2$, S3$, S, I
390: IF ((S1$<>SC$) OR ((Left$(S2$, 3))<>SP$
     And (S3$<>"")) Then GoTo 380
400: IF S3$<>"" Then GoTo 350
410: PRINT "NO MORE Species"
420: INPUT "LIST AGAIN? Y/N"; YN$
430: IF YN$ = "N" Then GoTo 20      Should be 10
440: Restore: GoTo 380
450: GoTo 530
460: Wait 105
470: PRINT "INSERT CROPS"
480: PRINT "BBBBBBBB Values"
490: INPUT "INTERCEPT? "; I
510: INPUT "SLOPE? "; S
```

```
530: INPUT "AIR Temp? "; TA
550: INPUT "CROPS Temp? "; TC
570: INPUT "REL Humidity? "; HL
580: Pause "CALCULATING"
590: Wait
600: T1 = TA + 273
610: TS = 373.16
620: R1 = TS/T1
630: P1 = -7.90298*(R1-1) + 5.02808*LOG R1
640: P2 = -1.3816*(10^(-7))*(10^(11.344*(1-T1/TS)-1))
650: P3 = 8.1328*10^(-8)*(10^(-3.19149*(TS/(T1-1)))-1)
       + LOG(1013.246)
660: Pause "CWSI"
670: E1 = 10^(P1+P2+P3)/10
680: E2 = E1*HL/100
690: V = E1-E2
700: U1 = (T1+I) + 0.16
710: Y5 = 0.1*EXP(18.7209 - 3806.41/U1 - 222152/(U1^2))
720: D = TC-TA
730: C9 = I + S*(V)
740: B1 = D - C9
750: V1 = Y5 - E1
760: C8 = I + S*(-V1)
770: A2 = C8 - C9
780: C2 = B1/A2
790: YN$ = "1": T1$ = " CROP IS "
795: IF SC$ = "" Then GoTO 885
```

```
800: T2$ = " DURING"
810: T3$ = " Species is "
820: IF S2$<>"" THEN GOTO 830
825: T2$=" "
830: wait (missing command)
840: FOR J = 1 to 38
850: Wait 20
860: SC$= Mid$ ((T1$ + S1$ +T2$ + S2$ + T3$ + S3$), J, 16)
870: PRINT SC$
880: NEXT J
885: Wait
890:  T1$ = "VPD"
900: T2$ = "ADJCWSI"
910: T3$= "^^^^^^^^ ###.####"
920: PRINT USING T3$; T2$, C2
930: PRINT USING T3$; T1$, V
940: INPUT "FINISHED? Y/N "; YN$
950: IF YN$ = "Y" THEN GOTO 970
960: GOTO 10
970: END
980: DATA "Cotton", " ", "G.hirsutum L.", -2.09, 1.49
990: DATA "", "", "", 1, 1
```

error

Parameters too small

My addition:

```
981: DATA "CORN", "pre-tassel", "DAVE DUNN SPECIAL", -2.056, 2.67
```

crop — stage of growth — species(hybrid) — slope — Intercept

```
982: DATA "CORN", "pre-tassel", "STEVE", -2.056, 2.67
```

```
*
      IR      = Trelc + Tir
      Trelc   = (1.0521 * Trel) - 0.2052
      Trel    = M * (-110.472 + (3.9105 * Tmv))
      Tmv     = SQRT(MilliVolts + 800)
      M       = (-0.00225 * Tir) + 1.0591
      Tir     = IR detector temperature

                                 Full Scale A/D Volts                    2.5V
      Volts = Ir Counts * ---------------------------- = Ir counts * ----------
                                 Full Scall A/D Counts                 4000 counts

*/
```

Everest transfer function
1986

ENERGY BALANCE DERIVATION of R_c 10 JUNE 1987

$$\frac{\varrho c_p (e_c^* - e_a)}{\gamma (r_a + r_c)} = R_N - G - \left(\frac{T_c - T_a}{r_a}\right) \varrho c_p$$

$$\frac{\varrho c_p (e_c^* - e_a)}{\gamma} = R_N (r_a + r_c) - G(r_a + r_c) - \left(\frac{T_c - T_a}{r_a}\right) \varrho c_p (r_a + r_c)$$

$$\frac{\varrho c_p (e_c^* - e_a)}{\gamma} = R_N r_a + R_N r_c - G r_a - G r_c - (T_c - T_a)\varrho c_p - \left(\frac{T_c - T_a \varrho c_p}{r_a}\right) r_c$$

$$= R_N r_a - G r_a - (T_c - T_a)\varrho c_p + R_N r_c - G r_c - \left(\frac{T_c - T_a}{r_a} \varrho c_p\right) r_c$$

$$\frac{\varrho c_p (e_c^* - e_a)}{\gamma} - R_N r_a + G r_a + (T_c - T_a)\varrho c_p = \left[R_N - G - \left(\frac{T_c - T_a}{r_a} \varrho c_p\right)\right] r_c$$

$$\frac{\left[\frac{\varrho c_p (e_c^* - e_a)}{\gamma} - R_N r_a + G r_a + (T_c - T_a)\varrho c_p\right]}{\left[R_N - G - \left(\frac{T_c - T_a}{r_a}\right)\varrho c_p\right]} = r_c$$

Note: 1) $R_N - \left(\frac{T_c - T_a}{r_a}\right)\varrho c_p - G$ CANNOT be NEGATIVE

2) r_c CANNOT be NEGATIVE

3) $\varrho c_p (e_c^* - e_a)$ CANNOT be NEGATIVE

4) $\frac{\varrho c_p (e_c^* - e_a)}{\gamma} - \left[R_N r_a - G r_a - (T_c - T_a)\varrho c_p\right]$ CANNOT be NEGATIVE

1) $\lambda = 2500 - 2.359\,TA$ (J/g) (TA is in °C)

2) $\frac{1\,W}{m^2} = \frac{1\,J}{Sec\,m^2}$

3) $1\ Acre = 43{,}560\ ft^2$

4) $1\ m^2 = 10.76\ ft^2$

5) $1\ g\ of\ H_2O = 1\ ml = 1\ cm^3$

6) $1\ m^2 = (100\ cm)(100\ cm) = 1 \times 10^4\ cm^2$

$$\frac{1\,J}{Sec\,m^2} \cdot \frac{}{2500\ J/g} = \frac{1\,g}{2500\ Sec\,m^2}$$

$$\frac{1\,g}{2500\ Sec\,m^2} \cdot \frac{cm^3/g}{m^2 \cdot 10000\ \frac{cm^2}{m^2}} = \frac{cm^3}{2500\ Sec\,cm^2} = \frac{cm \cdot (3600\ Sec)}{2500\ Sec\ hour}$$

$$= \frac{3600\ Sec}{hour} \cdot \frac{cm \cdot 1\ inch}{2500\ Sec\ 2.54\ cm} = \frac{inches}{hour}$$

$$\therefore \frac{1\,J}{Sec\,m^2} \cdot \frac{}{\lambda(J/g)}$$

$$\left[\frac{J}{Sec\,m^2}\right]\left[\frac{1}{2500\ J/cm^3}\right]\left[\frac{1\,m^2}{10{,}000\ cm^2}\right] \cdot \left[\frac{3600\ Sec}{hour}\right]\left[\frac{1\ inch}{2.54\ cm}\right]$$

$$= \frac{inches}{hour}$$

$$\boxed{\left[5.669 \times 10^{-5}\right] \times \frac{W}{m^2} = \frac{inches}{hour}}$$

$$= \frac{0.1417}{\lambda}$$

ET Model

Oct. 15, 1987

$$ET_{daytime} = R_N - \frac{\rho c_p (T_c - T_a)}{r_a} \quad (w/m^2)$$

T_A = Average T_A

T_C = Average T_C [after R_S exceeds 50 w/m^2 or Sunrise to Sunset (R_S is less than 50 w/m^2)

IF R_S is < 50 w/m^2 during the day, the sky is very dark (rain, etc.)]

Note: use Running Averages

Note: based on Latitude & Longitude, we can calculate Sunrise & Sunset daily to within a few minutes So we can always know if the Low R_S is caused by the weather or by Sunset/Sunrise (night).

* ET_{day} cannot be less than zero

$ET_{night} = 0.1\ ET_{day}$. (w/m^2)

R_N = Net radiation (w/m^2)

$$R_N = 0.77 R_S - \sigma T_S^4$$

R_S = Incoming Solar heat Load (w/m^2)

$T_S = [\ T_c + 273.1\ ]$

T_c = Crop Temp $(^\circ C)$

$\sigma = 5.67 \times 10^{-8}$

$\rho c_p = 1294.1$

$r_a = 50 - 4.0\,U$ (sec/m)

U = Average windspeed in mph
if mph > 10 , Then mph $= 10$
(the minimum $r_a = 10$)
maximum $r_a = 50$

$ET_{daily} = ET_{day} + ET_{night}$ (W/m^2)

To convert W/m^2 to inches/day,
multiply by 1.3884×10^{-3} X

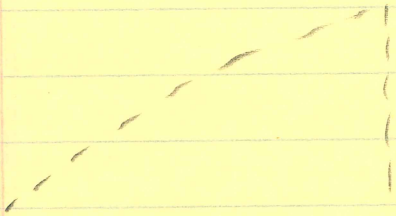
question : Sampling frequency?
Answer : as often as possible : Keep a running Average

To compute U :

$$\frac{\text{current windrun value} - \text{last windrun}}{\Delta \text{time (hours)}} \text{ (miles)}$$

on a daily Basis, Keep track of

(Σ ET daily) (graph this)

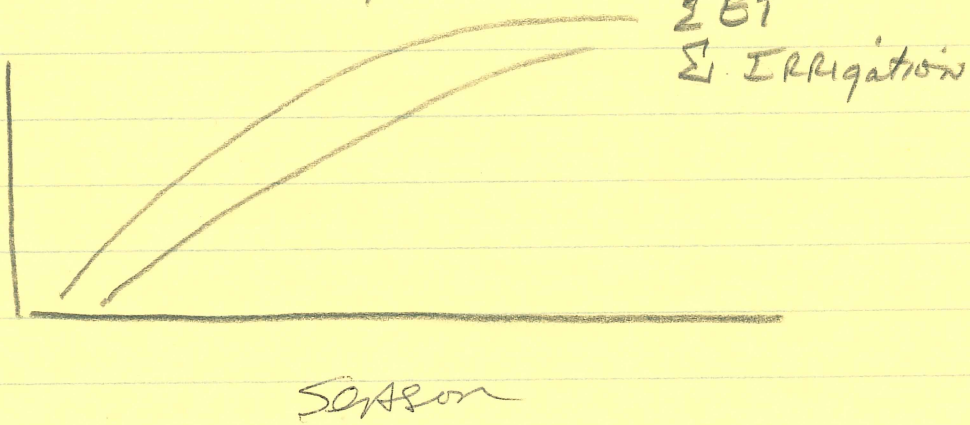


Reset the Σ to zero whenever a precipitation or rainfall event occurs (Rainfall exceeds Σ ET)

* One comparison:

Σ ET daily versus Σ Irrigation Amts

(They should track very well).



& CWSI : use Average Max T_c and Associated T_a, RH during 12:00 - 3:00, ~~provided R_s is greater than 65%~~

OR use the JACKSON equation for CWSI

★ OR use :

$$\left[1 - \frac{ET}{ET_p}\right] * 10$$

where ET is our estimate of ET (from 12:00 - 3:00) and ET_p is the PENMAN ET_p estimate during this time interval

Note ET cannot exceed ET_p

$$ET_p = \frac{\Delta}{\Delta+\gamma}(R_N) + \frac{\gamma}{\Delta+\gamma}\frac{(VPD)\cdot\rho c_p}{r_a}$$

$$\gamma = 0.066$$

$$\Delta = VPS\left[\frac{4098.02582}{(T_A + 237.3)^2}\right]$$

$$VPS = 0.61078 \exp\left[\frac{17.2694\, T_A}{T_A + 237.3}\right]$$

ET Model Nov. 3, 1987

Measurements

		Symbol
1.	Crop Temp (°C)	T_C
2.	Air Temp (°C)	T_A
3.	Incoming heat Load	R_S

Constants

		Symbol	Value
1.	Aerodynamic Resistance	r_a	30
2.	Conversion Factor # 1	ρ_{cp}	1294.1
3.	Conversion Factor # 2 ($W/m^2 \rightarrow \frac{inches}{hour}$)	CF	5.7849×10^{-5}

Calculated Variables

1. Diff = $T_c - T_a$
2. $R_N = 0.77 * R_S$ (Net Radiation)
3. $G = (0.3) * R_N$ (turf) (Soil Heat flux)
   $(0.1) * R_N$ (crops)

The multiplier for G is a function of crop, ground cover, and surface soil moisture

Model : Daytime ET calculations only

1. Calculate LE using 1/2 hour Averages of T_C, T_A, and R_S

2. Negative ET values are not permitted

3. IF $(T_C - T_a) > 10$, Then use a value of 10 in the ET calculation

4. IF $(T_C - T_a) < -10$, Then use a value of -10 in the ET calculation

5. R_S Must be > 50, i.e., daylight conditions Must exist. It is easy to calculate sunrise + sunset times for a given Location

6. Night-time ET is assumed to be $\frac{1}{10}$ of the daytime ET.

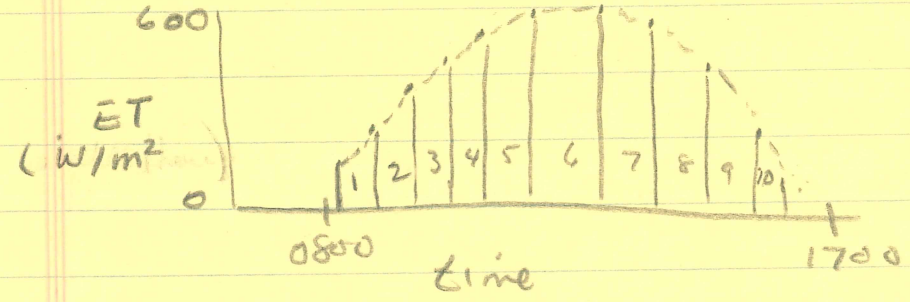
7. Accuracy would be enhanced with a soil heat flux plate. G can be variable depending on the crop, stage of growth and soil Moisture

Model calculations

1. $ET = R_N - (\rho c_p (T_c - T_a)/r_a) - G$
   (Answer is in W/m^2

2. To convert to inches per hour
   $ET = ET * 5.7849 \times 10^{-5}$

3. Use Trapezoidal Rule to Integrate, using ½ hour Averages



example,

1st obs , ET = 0 , Time = 800
2nd obs , ET = 50 W/m² Time = 830

1st ET calculation = $\frac{(ET_2 - ET_1)}{2} \cdot (\text{time } 2 - \text{time } 1)$

$= \left(\frac{50-0}{2}\right)(8.5 \text{ hrs} - 8.0 \text{ hrs}) = 12.5 \frac{W}{m^2} \cdot hr$

This total is Added to the succeeding observations

ET-hours = $\frac{1}{2} \sum_1^N (ET_2 - ET_1)(\text{time}_2 - \text{time}_1)$

At the end of the day, we have the total AREA under the curve in $\frac{W}{M^2} \cdot hr$

- divide this total by the total number of hours in the day:

$$\frac{ET\text{-hours}}{(Time(last) - Time(first)} = ET_{Average}$$

- This produces the Average ET in $\frac{W}{m^2}$ for the day

- Convert ET_{Avg} (W/m^2) to $(inches/hour)_{Avg}$

$$ET\left(\frac{inches}{hour}\right)_{Avg} = ET_{Avg}\,(W/m^2) * 5.7849 \times 10^{-5}$$

- The total ET is then $ET\left(\frac{inches}{hour}\right)_{Avg} \cdot (\text{total time})$

Example: Average ET = 350 W/m^2 for a 12 hour day.

$\therefore$ $ET_{Avg} = 350\ W/m^2$

$\therefore$ $ET\left(\frac{inches}{hour}\right)_{Avg} = 2.024715 \times 10^{-2}\ \frac{inches}{hour}$

$\therefore$ $ET(total) = (2.024715) * 12\ hours = 0.24\ inches$

12 April 1988

Orange Index – New Concept

general

$$\text{Index} = 10\left[1 - \frac{ET}{ETp}\right]$$

(1) ET estimate

$$ET = R_N - \frac{\rho c_p}{r_a}(T_c - T_a)$$

$R_N = 0.77 R_S - \sigma T_c^4$

$\rho c_p = 1294.1$

$\sigma = 5.67 \times 10^{-8}$

$r_a = 50 - 4.0\,U$ (U is in mpH)

if wind = 0 (mpH), $r_a = 50$

if wind = 1–5, $r_a = 35$

if wind = 5–10 $r_a = 20$

if wind ≥ 10 $r_a = 10$

(2) ET_p estimate

$$ET_p = \frac{\Delta}{\Delta+\gamma} R_N + \frac{\gamma}{\Delta+\gamma} \cdot f(u) \cdot VPD$$

$f(u) = 0$, if wind = 0

$f(u) = 15$ if wind 1–5

$f(u) = 35$ if wind 5–10

$f(u) = 50$ if wind ≥ 10

$f(u) = 4.9$ (wind) (wind is in mph)

$= 4.9 * u$

(2) continued

(2) $R_N = 0.77 \cdot R_S$

$R_S = f(\text{Latitude, Day of year})$ ≈ 1000 for Oranges
Leaf ⊥ to Sun

$$\Delta = VPS \left[\frac{4098.025\,82}{(T_A + 237.3)^2} \right]$$

VPS = already in Scheduler

$$= 0.61078 \times EXP \left[\frac{17.269\,3882 * T_A}{T_A + 237.3} \right]$$

$\gamma = 0.066$

(3) $$Index = \left[6.0 - 10 * \frac{ET}{ET_p} \right]$$

Note K_c of Oranges ≈ 0.6 all year

$K_c = 0.6$ = Index of 6

ORANGES
4.74 – 1.27 VPD, Max = 8

Notes: Bronson
Gardner
12/7/88

Issues of Concern

- Turf Baseline – a single, or even small group of turf baselines does not look practical. The turf baseline is affected by:
  - Management practices – different everywhere
  - time of year / time of day effects
  - "window of opportunity" changes from summer to winter
  - interpetation problems – users want agronomic answers to questions no one really knows the answer to.
- Citrus/ Oranges – crop physiology makes it impossible to use the Scheduler. Citrus/ Orange tree leaves evaporate water slowly. Crop Link may solve the ET problem in citrus, however
- Forage Alfalfa – baseline needs adjusting. Data is available to do this
- Potatoes – Scheduler is proven successful at monitoring stress. Baseline is confirmed. Researchers cannot confirm the ability of the index to schedule irrigations. Intensive data analysis/ perhaps more research required. Crop Link Solution?
- Celery – may be grown in a climate too cool to generate significant stress levels much of the time. Crop Link probably required.
  - Ditto for lettuce.

- Grapes - wine grapes (Napa area) Area experiences fequent cool cloudy weather. CropLink Solution?

- Grower training
  - proper instrument use - rules of cleaness, equilibration violated frequently
  - repeat visits to insure proper use is often needed
  - few understand how to effectively sample their farm
  - few comprehend how to interpet their data beyond a simple threshold
  - Grower biases inhibit acceptance of instrument readings. Growers want a fully documented, proven 1:1 relationship between their stress index and their favorite scheduling technique. The index is correlated with these techniques (soil moisture, pressure bomb, tensiometers) but 1:1 calibrations don't exist. Growers view whatever current technique they use as "correct", requiring the Scheduler to simply duplicate their current procedures. Few view the Scheduler as a different, unique approach that should not be compared on a 1:1 with other techniques.

- Dealer/Salesmen training. Inspite of repeated educational efforts, The Schedule is not effectively understood by Those Representing it.

- New Crops. Potential customers ~~seem~~ are often interested in crops we have no knowledge of (bananas, Avocados, etc. etc.). Over 100 baselines would be required to satisfy most of The U.S. and international market. clearly ~~an~~ a task that is too large. Customers will wait until Their particular baseline is ready. Alternate approaches to interpreting The data are required, (Software begun, but has a ways to go).

- Computers. Salesmen/dealers/growers don't understand Them very well. Communication bugs between The Scheduler and P.C.'s occur fequently. While usually easily solved by a Knowledgable technical person, There are still periodic failures in The effort to Communicate. Often The process takes 1-2 hours to accomplish during an on-site visit, often with The aid of our 800 number to provide The dealer/Salesmen with step-by-step instructions. I'm concerned when I keep giving The same person The same instructions over and over.

- time to validate a baseline. This process cannot be speeded up. The process:
  - 1 crop season for initial data / baseline
  - 1 crop season to test first baseline and make adjustments, determine "practicality"
  - ~~a~~ a 3rd season may be required, to make final adjustments
    - reliability / agronomic expertise / record keeping / analytical ability of the researcher is critical to success.
- Research attitude - The agronomy society is not unanimous in its acceptance of infrared technology. Like consultants, the Scheduler infringes on the expertise of many researchers who jealously protect their territory. Recently, a noted IRT expert from Israel claimed his computer model "proved" IRT's were not a practical tool and should be abandoned. His data, however, simply supported our training manuals. Some researchers strongly support this technology, a few oppose it, and most seem uninterested. More aggressive activity in the research community is needed:
  - professional articles
  - Symposiums
  - Seminars
  - Committees

all this does is establish credibility and name recognition, but is essential. It also takes years.

- Scheduler hardware has problems
  - Air Temperature accuracy is a concern
  - Solar radiation reading is unstable, even on a clear day
  - processor is slow, with inadequate memory / power to contain some very useful routines
  - (Equilibration time / case temperature effects on a hot day)

. Competitor may have a technically superior product. Eventually somebody will publish a head-to-head comparison.

Scheduler Software needs

- faster data processing
- more statistics, especially when baseline is suspect
- user-defined calibrations - useful 1-2 years after purchase to verify sensors have not drifted. Currently, if sensors drift, but still work, "that's just too bad".

Perception Problems (Sales Resistance)

- 64K computers are cheap on today's Market ($100-200)
- RH/Temperature probes are cheap ($200)
- photocells are cheap ($5-10 for high quality)
- IRT's cost between $1000 and $2,400.
- Customers (I believe) estimate the Scheduler should cost between $1,400 and $2800. Packaging / programming / experience are probably only worth a few hundred additional dollars.

12 April 1988

Orange Index – New Concept

general

$$\text{Index} = 10\left[1 - \frac{ET}{ETp}\right]$$

(1) ET estimate

$$ET = R_N - \frac{\rho c_p}{r_a}(T_c - T_a)$$

$R_N = 0.77 R_S - \sigma T_c^4$

$\rho c_p = 1294.1$

$\sigma = 5.67 \times 10^{-8}$

$r_a = 50 - 4.0\,U$ (U is in mph)

if wind = 0 (mph), $r_a = 50$

if wind = 1–5, $r_a = 35$

if wind = 5–10, $r_a = 20$

if wind > 10, $r_a = 10$

(2) ETp estimate

$$ETp = \frac{\Delta}{\Delta+\gamma} R_N + \frac{\gamma}{\Delta+\gamma} \cdot f(U) \cdot VPD$$

$f(U) = 0$, if wind = 0

$f(U) = 15$ if wind 1–5

$f(U) = 35$ if wind 5–10

$f(U) = 50$ if wind > 10

$f(U) = 4.9$ (wind) (wind is in mph)

$= 4.9 * U$

(2) continued

(2) $R_N = 0.77 \cdot R_S$

$R_S = f(\text{Latitude, Day of year})$ ≈ 1000 for Oranges
Leaf ⊥ to Sun

$$\Delta = VPS \left[\frac{4098.02582}{(T_A + 237.3)^2} \right]$$

VPS = already in Scheduler

$$= 0.61078 \times EXP \left[\frac{17.2693882 * T_A}{T_A + 237.3} \right]$$

$\gamma = 0.066$

(3) $$Index = \left[6.0 - 10 * \frac{ET}{ET_p} \right]$$

Note K_c of Oranges ≈ 0.6 all year

$K_c = 0.6$ = Index of 6

ORANGES
4.74 – 1.27 VPD, Max = 8

12 April 1988

TURF Correction

IF Doy $\leq$ 91

A = Current Intercept
Max = Current Max

$$A = (A-6) + 0.0671 * Doy$$
$$Max = (Max-6) + 0.0671 * Doy$$

IF Doy > 91 and Doy L 274 — No change

IF Doy > 274

$$A = A - 0.0654(Doy-274)$$
$$Max = Max - 0.0654(Doy-274)$$

$7.0 - 1.9 * VPD$ Max = 13.0

ST27

TURF Adjustment

	Intercept	Slope	Max
January	2.0	-1.9	8
Feb	3.3	-1.9	9
March	4.6	-1.9	11
April	6.0	-1.9	12
May	7.0	-1.9	13
June	7.0	-1.9	13
July	7.0	-1.9	13
Aug.	7.0	-1.9	13
Sept	6.0	-1.9	12
Oct	4.6	-1.9	11
Nov.	3.3	-1.9	9
Dec.	2.0	-1.9	8

CLV 193-C

SHEET NO. ____ OF ____

FILE ____

SUBJECT 15 Minute TA Variation

DATE 1 June 1988

BY BJ

Wind

1	~~Start~~	84.3			86.1 no wind
2		83.9		1:45	86.0
3		83.8			85.6
4		83.6			85.5
5		83.8			85.4
6		83.5			84.3
7		83.7 no wind		2:00	~~83.6~~
8		83.5			~~83.5~~
9		83.3			83.4
10	30 Sec.	83.1			~~83.5~~ no wind
11		83.3			83.8
12		82.9			83.7
13		83.3			83.8
14		83.3		2:15	83.7
15	45 Sec.	84.1			83.8 no wind
16		84.5 gust			84.2
17		84.6			84.6
18		84.4			84.9
19		84.8			85.1
20	1 min	84.7 0 wind			85.5
21		84.4		2:30	~~85.6~~
22		~~84.6~~			85.7
23		84.7			~~85.6~~
24		85.0			85.4
25		~~84.8~~			85.0
26	1:15	84.7 gust			85.1
27		85.5		2:45	~~84.9~~
28		~~85.4~~			84.6 wind
29		~~84.8~~			84.9
30		84.9			85.2
31		~~85.0~~			85.9 gust
32		85.2			~~86.0~~
33		85.8		3:00	~~85.7~~ 3 minute
34	1:30	86.3			85.5 3 minute
35		86.6			85.3
36		86.8			84.8
37		86.6 5-6 mph			~~84.5~~
38		86.2			85.3

CLV 193-C

SHEET NO. _____ OF _____

FILE _____

SUBJECT _____

DATE _____

BY _____

3:00	85.3		85.8		85.2			
	~~84.8~~		84.2		~~85.0~~			
	84.5		85.5		84.9			
	85.3		~~84.9~~		~~85.1~~			
3:15	86.0		84.7		85.4			
	86.1		4:45 84.9		6:15 86.3			
	~~86.3~~		84.5		85.8			
	86.4		84.3		~~85.1~~			
	85.9		~~84.7~~		~~85.4~~			
	85.2		5:00 84.9		84.6			
	~~85.6~~		~~85.1~~		~~84.8~~			
3:30	85.6		85.1		6:30 84.8			
	86.0		85.5		84.7			
	86.4		85.4		84.8			
	~~85.7~~		84.8		84.9			
3:45	85.6		5:15 84.9		84.2			
	85.7		~~85.3~~		83.5			
	86.0		85.4		2:45 83.6			
	86.3		84.8		83.0			
	~~86.2~~		84.9		82.5			
	~~85.8~~		85.3		82.9			
4:00	84.2		85.5		83.6			
	84.8		85.4		84.5			
	85.2		5:30 85.6		7:00 ~~84.9~~			
	~~85.0~~		85.4		85.2			
	~~85.3~~		~~86.0~~		85.4			
	85.0		~~86.0~~		85.3			
	84.8		85.5		~~85.0~~			
4:15	~~85.1~~		85.0		85.1			
	85.2		5:45 ~~85.3~~		85.5			
	85.0		~~85.2~~		85.5			
	85.5		~~85.0~~		85.6			
	~~85.7~~		84.7		85.7			
	85.9		~~84.7~~		86.2			
4:30	85.5		84.8		85.9			
	85.3		4:02 84.7		7:30 ~~85.4~~			
	85.6		85.1		84.8			

CLV 193-C

SHEET NO. _____ OF _____

FILE _____

SUBJECT _____

DATE _____

BY _____

1			84.7			9:00	84.1			85.4	
2			85.1				84.1			85.5	
3	7:45		84.7				84.2			85.6	
4			84.5				84.0			86.0	
5			84.5				Restart			86.2	
6			83.8			9:30	84.4			86.0	
7			83.2				85.0			85.8	
8			83.1				85.5			85.8	
9		8:00	83.2				85.3			85.7	
10			83.2				85.1			85.4	
11			83.4				84.9		11:00	85.4	
12			83.8				84.9			85.5	
13			83.8				85.1			85.8	
14			84.2				85.2			85.0	
15			83.7				85.2			84.8	
16			83.3				85.1			85.4	
17			83.3				85.4			86.1	
18			83.2				85.6			86.4	
19			83.2				85.5			86.5	
20			83.7				85.7			86.3	
21			84.2				85.5			86.3	
22			84.2				85.4			86.0	
23			84.1			10:00	85.5			86.1	
24			84.0				85.5			86.0	
25			84.0				85.3			85.9	
26			84.0				85.1		11:30	85.8	
27			84.2				85.3			85.1	
28			83.7				85.7			85.0	
29			83.4				85.3			85.1	
30			83.3				85.3			85.2	
31			83.2				85.3			84.6	
32			83.4				85.2			84.5	
33			83.7				85.2			84.9	
34			84.1				84.5			85.1	
35			83.6				84.6			85.2	
36			83.1				84.2			84.8	
37			82.9				84.9			84.6	
38			83.3				85.2				

CLV 193-C

SHEET NO. _____ OF _____

FILE _____

SUBJECT _____

DATE _____

BY _____

			84.5				84.9			84.9	
			84.5				84.7			84.8	
			84.7				84.8			84.7	
	12:00		84.7				85.0			84.6	
			84.7				84.8			84.7	
			84.9				84.8			84.7	
			84.9				83.8			84.9	
			85.2				83.6			84.8	
			85.4				83.9			84.8	
			84.9				84.3			84.5	
			84.5			13:30	84.4			84.6	
			84.5				84.5			84.8	
			84.6				84.6			85.0	
			84.5				84.5		15:00	84.9	
			84.5				84.8				
	12:30		84.6				84.8				
			84.6				84.6				
			84.5				84.5				
			84.7				84.9				
			84.6				85.0				
			84.5				84.5				
			84.7			14:00	84.2				
			84.7				84.1				
			84.7				83.9				
			84.7				84.0				
			85.0				84.1				
			85.1				84.3				
			85.1				84.3				
	13:00		85.4				84.4				
			85.1				84.1				
			84.6				84.3				
			84.9				84.3				
			85.0				84.4				
			85.2				84.6				
			85.2				84.9				
							84.9				
						14:30	85.0				

CLV 193-C

SUBJECT

SHEET NO. OF

FILE

DATE 5/31/88

BY CGS

Same as standard indoors

#252 – #

Reads low 0.2–0.3 compared to standard indoors

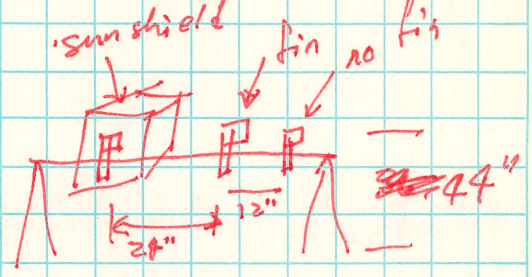
Mod'd Unit # 670

Unmod # 495

Time	T_{AIR}	$T_{AIR,STD}$	T_{AIR}
inside 0	73.2		73.2
1:30	83.1		82.9
~~3:00~~	~~84.4~~	~~83~~	~~81.2~~
3:45	80.4	83.1	80.7
4:15	81.8	83.0	82.0
4:45	82.6	84.2	82.7
5:30	82.8	85.3	83.2
6:00	83.6	85.7	83.5
6:30	83.6	86.0	83.8
7:10	83.6	85.6	83.7
7:40	83.3	84.9	83.4
8:10	83.5	85.5	83.5
8:40	83.4	84.3	83.3
9:10	83.4	84.5	83.2
9:40	83.4	84.7	83.6
10:40	83.3	84.7	83.8
11:10	82.7	83.7	82.8
11:40	83.5	84.1	84.0
12:10	82.9	84.1	82.5
12:40	82.6	84.1	82.5
13:10	82.7	84.1	82.6
13:40	82.6	83.2	82.6
14:10	83.0	84.0	83.1
14:40	82.9	84.4	83.0
15:10	83.6	84.5	83.4
15:40	83.2	83.5	82.9
16:15	82.4	83.9	82.0
16:45	83.2	83.9	83.2
17:45	82.3	83.6	82.9
18:45	82.2	83.2	82.4
19:45	82.6	83.7	82.4
22:30	84.1	84.4	84.1
24:00	83.9	84.4	84.2
26:00	83.8	84.9	84.0
28.00	82.4	83.6	82.1

NOTES

Breezy



Sun 82

Sun 82

CLV 193-C

SUBJECT

Pointed @ Cement IR: 95°

Pointed @ Sky / Woods IR: 69°

SHEET NO. 2 OF

FILE

DATE 5/31/88

BY

		MOD'D	STD	UMOD	
1	30:00	84.8	85.2	85.5	RH 35% Sun 82-84
2	32:00	84.7	85.2	85.2	
3	34:00	82.6	83.8	82.7	
4	36:00	83.3	83.7	84.1	
5	38:00	83.8	85.4	84.5	1 seconds later - all read
6	40:00	84.1	84.4	84.2	Sun 82, 84 (86.0) RH - 32% each one
7					
8					
9					
10					
11					
12					
13					
14	Sun behind & to left; sun shone on LHS of pistol —				
15	so far, no noticeable diff due to sun load; LHS notably				
16	warm — RHS notably cool to touch.				
17					
18					
19					
20					
21					
22					
23					
24					
25					
26					
27					
28					
29					
30					
31					
32					
33					
34					
35					
36					
37					
38					

Test 2, same pistols - rotated so sun hits Rhts (sensor side). After sitting outside w/out fans on, for 2 hrs. Units on for several minutes before test starts (ie, ~5 mins). Units' Rhts exposed to sun only ~~after~~ " after machines on.

TIME	MOD'D	STD	UNMOD	[Looking for solar bias.]
0:00	87.9	88.0	88.0	
2:00	86.6	86.5	87.4	
3:00	88.4	87.7	88.7	
4:00	87.0	86.6	87.7	← Unmod runs ½ - 1°F hotter than mod'd, typ. Both higher than shaded Std.
~~5:00~~	89.0	88.3	89.3	
~~6:00~~ 7:00	86.3	86.6	86.2	
8:00	86.9	86.0	86.2	
9:00	87.1	87.3	87.6	
10:00	86.8	86.6	87.8	
11:00	87.5	87.0	88.0	

@12:00, BRG removed from holder, held ~~55~~ 5

~~24:0~~ 22:12 guns across board

8	84.7	85.9	84.7	
	87.5	85.7	89.9	24:00

CLV 193-C

SHEET NO. ____ OF ____

FILE ____

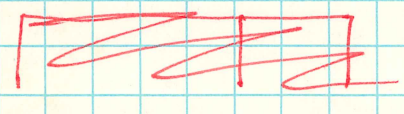
SUBJECT ____

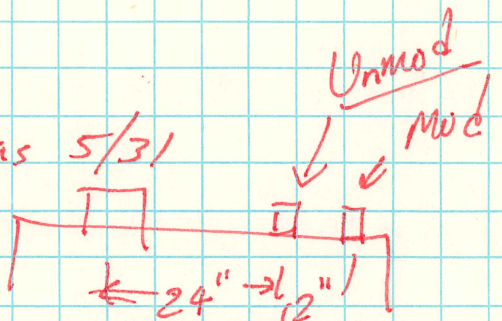
DATE 6/1/88

BY CJB

Winds 0-5, gusting to 10 mph
~85°F
RH 33%

Equil. of same two units as 5/31





Time	STD	Unmod	Mod
2:10	83.1	92.0	92.8
2:40	84.2	90.6	87.4
3:10	84.1	93.2	89.9
3:40	85.0	93.8	90.5
4:10	86.1	97.0	94.9
4:40	85.7	96.2	94.6
5:10	84.8	91.7	90.4
5:40	86.0	93.1	91.6
6:10	85.4	91.8	91.7
6:40	85.0	91.8	89.9
7:10	85.3	92.4	90.6
7:40	85.4	90.5	88.7
8:10	83.6	86.2	86.3
8:40	83.8	84.6	84.8
9:10	85.9	90.4	89.3
9:40	83.2	84.0	83.7
10:10	84.4	86.9	86.0
10:40		84.6	84.5
~~11:10~~			
~~11:40~~	Units timed out/countdown		
~~12:10~~			
12:40	84.0	88.7	88.4
13:10	84.8	85.5	85.0
12:40	83.5	84.9	84.5
14:10	85.2	87.4	86.6
14:40	84.3	85.0	84.8
15:10	84.0	85.6	85.3

Time Ø was when units brought to "horse" - both were exposed to air from car (not bagged) - 58°

Units seem sensitive to wind speed

CLV 193-C

SHEET NO. 2 OF

FILE

SUBJECT

DATE 6/1

BY CTS

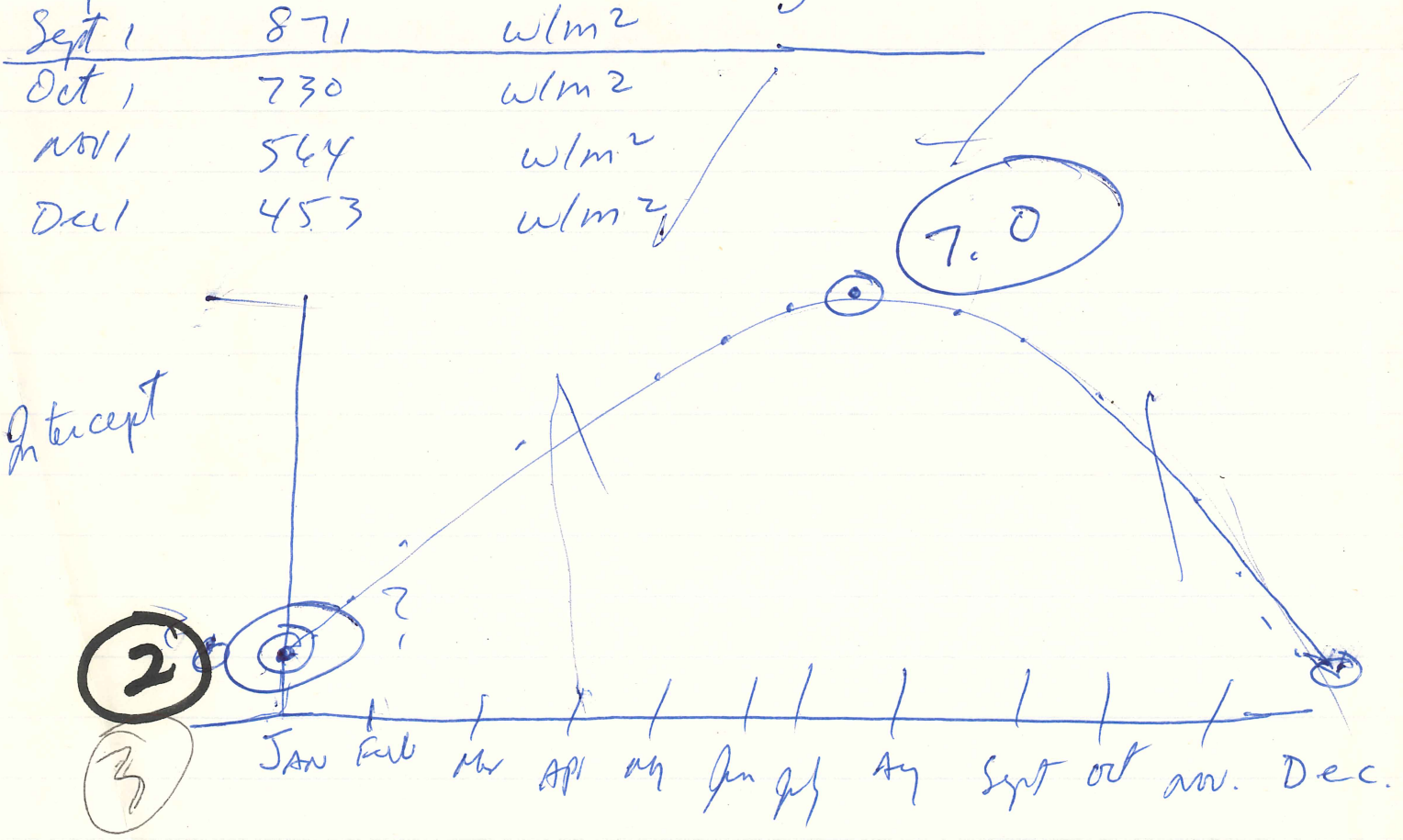
		SID	UnMod	Mod
1	15:40	84.0	84.3	84.5
2	16:10	85.1	86.5	86.1
3	16:40	86.1	87.9	87.3
4	17:10	85.6	87.0	87.0
5	17:40	85.9	87.6	87.3
6	18:10	86.9	88.4	87.8
7	~~18:40~~ →	83.7	84.1	84.3
8	19:10	~~- - - -

33°N Latitude

Solar Noon (Incoming Radiation)

Jan 1	442	w/m²
Feb 1	540	w/m²
Mar 1	687	w/m²
April 1	843	w/m²
May 1	938	w/m²
June 1	977	w/m²
July 1	980	w/m²
Aug 1	953	w/m²
Sept 1	871	w/m²
Oct 1	730	w/m²
Nov 1	564	w/m²
Dec 1	453	w/m²

7° one



M

Memo:
Steve DeSutter

Re: Theory

We have known for some time that the baselines ~~appear~~ are ~~the slope~~ affected by changes in ambient conditions. I have established the following theoretical chart that demonstrates a baseline is a very ~~strong~~ dependent on air temperature:

Air Temperature	Theoretical Intercept	Theoretical Slope (no crop factor)
68	1.4	−1.01
75	1.6	−1.24
80	1.8	−1.40
85	1.8	−1.57
90	2.2	−1.81
95	2.4	−2.07
100	2.7	−2.30

(R_N = 900 w/m²)

The theoretical slope and intercept should be slightly modified for each crop, but this ~~slope~~ table is consistent with ~~the~~ the laws ~~of~~ environmental physics. Note the strong effect on the slope as temperature varies. The intercept varies with sunlight

~~and~~ (clouds + time of day), but not the slope. Both terms are ~~only affected~~ affected by windspeed.

I find T_c min

8/17/89 $C = \rho c_p$ (1)

$G = \gamma$

(JACKSON #8) $S = \Delta$

(1) $LE_1 = \dfrac{C(e_c^* - e_A)}{G(r_A + r_c)}$

$LE_2 = R_N - \dfrac{C(T_c - T_A)}{r_A}$

$\therefore \dfrac{C(e_c^* - e_A)}{G(r_A + r_c)} = R_N - \dfrac{C[T_c - T_A]}{r_a}$

$C(e_c^* - e_A) = G(r_A + r_c)R_N - \dfrac{C\,G(r_A + r_c)[T_c - T_A]}{r_a}$

$(e_c^* - e_a) = \dfrac{G}{C}(r_A + r_c)R_N - \dfrac{\cancel{C}\,G(r_A + r_c)[T_c - T_A]}{\cancel{C}\; r_a}$

$e_c^* - e_a = \dfrac{G}{C}(r_a + r_c)R_N - \dfrac{G(r_A + r_c)[T_c - T_A]}{r_A}$

$e_c^* - e_A = \dfrac{G}{C}(r_a + r_c)R_N + \dfrac{G(r_A + r_c)T_A}{r_A} - \dfrac{G(r_A + r_c)T_c}{r_a}$

$$\boxed{e_c^* + \frac{G(r_a + r_c)T_c}{r_a} = e_a + \frac{G}{C}(r_a + r_c)R_N + T_A\left(\frac{G(r_A + r_c)}{r_A}\right)}$$

$\therefore$ ~~Sout~~ solution for T_c min is iterative

II. Find T_c min a second way

$$\frac{LE_1}{LE_2} = \frac{R_N - C\,\dfrac{(T_c - T_a)}{r_a}}{\dfrac{C}{G}\left(\dfrac{e_c^* - e_a}{r_a + r_c}\right)} \qquad \text{(Blad)} \quad \text{Jackson}$$

$$\therefore = \frac{G(r_a+r_c)R_N - G(r_a+r_c)C(T_c - T_a)/R_a}{C\,(e_c^* - e_a)}$$

When $LE_1 = LE_2$, Num = Denom. T_c is at potential

$$G(r_a+r_c)R_N - \frac{G(r_a+r_c)C(T_c-T_a)}{r_a} = C(e_c^* - e_a)$$

$$\frac{G}{C}(r_a+r_c)R_N + \frac{G(r_a+r_c)}{r_a}T_A - \frac{G(r_a+r_c)}{r_a}T_c = e_c^* - e_a$$

$$\therefore \frac{G}{C}(r_a+r_c)R_N + G\left(\frac{r_a+r_c}{r_a}\right)T_A + e_a = e_c^* + G\left(\frac{r_a+r_c}{r_a}\right)T_c$$

divide by $\frac{r_a+r_c}{r_a}$

$$\frac{G}{C} r_a R_N + G T_A + e_a\left(\frac{r_a}{r_A+r_c}\right) = e_c^*\left(\frac{r_a}{r_A+r_c}\right) + G T_c$$

divide by G

$$\frac{r_a R_N}{C} + T_A + \frac{e_a r_a}{G(r_A+r_c)} = \frac{e_c^*(r_a)}{G(r_A+r_c)} + T_c$$

$$\frac{r_a R_N}{c} + T_A + \frac{e_a}{G\left(1+\frac{r_c}{r_a}\right)} = \frac{e_c^*}{G\left(1+\frac{r_c}{r_a}\right)} + T_c$$

$$\therefore T_c - T_A = \frac{r_a R_N}{c} + \frac{e_a}{G\left(1+\frac{r_c}{r_a}\right)} - \frac{e_c^*}{G\left(1+\frac{r_c}{r_a}\right)}$$

$$T_c - T_A = \frac{r_a R_N}{c} + \frac{e_a - e_c^*}{G\left(1+\frac{r_c}{r_a}\right)}$$

$$= \boxed{T_c - T_A = \frac{r_a R_N}{c} - \frac{(e_c^* - e_a)}{G\left(1+\frac{r_c}{r_a}\right)}} \quad \star$$

$\therefore$ measure T_A & $+ R_N$

guess $\frac{r_c}{r_a} + r_a$

then Guess (iterate) T_c show that the left side = right side

$$\therefore B\ (\text{slope}) = \frac{1}{G\left(1+\frac{r_c}{r_a}\right)} \quad \star$$

JACKSON (Slope) = $\frac{1}{\Delta + G\left(1+\frac{r_c}{r_a}\right)}$

EDS

if $LE = 0$, $Num = 0$

$\therefore$ $(r_A + r_C) R_N = \dfrac{C[r_A + r_C][T_C - T_A]}{r_A}$

$(r_A + r_C) R_N = \dfrac{C[r_A + r_C][T_C - T_A]}{r_A}$

$(r_A + r_C) R_A R_N = C[r_A + r_C][T_C - T_A]$

$R_A R_N = C(T_C - T_A)$

$\dfrac{R_A R_N}{C} = T_C - T_A$

$$T_{C_{Max}} = \frac{R_A R_N}{C} + T_A$$

= Identical to Jackson

LE/LEp

$$R_N - \frac{C(T_C - T_A)}{r_a}$$ (Blad

$$\frac{LE_1}{LE_2} = \frac{\dfrac{C(e_c^* - e_A)}{G(r_A + r_c)}}{}$$ Jackson

$$\therefore \frac{G(r_A+r_c)R_N - \dfrac{G \cdot C[r_A+r_c][T_C - T_A]}{r_A}}{C(e_c^* - e_A)}$$

at $r_c = 0$, Num = Denom

$$\therefore$$

$$G(r_A)R_N - \frac{G \cdot C \cancel{r_a}[T_C - T_A]}{\cancel{r_A}} = C(e_c^* - e_A)$$

$$\frac{G}{C} r_A R_N - G(T_C - T_A) = e_c^* - e_A$$

$$\frac{G}{C} r_A R_N + GT_A = e_c^* + GT_C - e_A$$

$$\boxed{\frac{G}{C} r_A R_N + GT_A + e_A = e_c^* + GT_C} = \text{minimum } T_c$$

Comparison of the ~~Daftaard~~ Scheduler Plant Stress Monitor and the Pressure Chamber for Cotton Irrigation Scheduling

Bronson Gardner, Standard Soil Materials Engineers
in Co-operation with
Lowell J. Zelinski, Farm Advisor
University of Calif, Cooperative Extension
and Crop Care Associates, Fresno

The Scheduler Plant Stress monitor was compared with leaf water potential readings ~~eth~~ collected with a pressure chamber device between July 8 and August 29, 1986, on ~~Ten~~ 27 plots of ~~cotte~~ cotton, on which three varieties and three irrigation treatments were imposed. The treatments were:

1) First irrigation at 15 bars
2) first irrigation at 19-20 bars
3) first irrigation at 23-~~25~~ bars

All other irrigations were at 19-20 bars.

Varieties:

1) Acala SJ-2
2) Acala SJC-1
3) Acala GC-510.

Insert from page (3) (2)

Data Analysis

Since the primary purpose of Scheduler and pressure bomb irrigation scheduling activities is to help growers maximize yields, the data was divided ~~into three groups : 1) plots w~~ according yield into three groups:
1) yields between 2.0 and 2.5 bales/acre
2) yields between 2.5 and 3.0 bales/acre
3) yields between 3.0 and 3.5 bales/acre.
The ~~min~~ minimum to and maximum readings of the Scheduler index and pressure chamber are given for each date. (Tables 1-3) ~~according to the yield grouping is Tables 1-3.~~

Discussion

The greatest ~~variability~~ range in index and pressure chamber readings occured in the highest yielding plots. (Table 3) In practical terms, this means 1) that plant to plant variability is normal and that a sufficient number of samples must be collected in order to insure that a representative average is obtain. ~~This~~ Taking enough data to

insure accuracy is a simple ~~batch~~ process with the Scheduler since it can acquire 4 samples per second. ~~For Each sample corresponds to the area~~ encompassed by approximately ~~A Scheduler sample can range between~~ A Scheduler Sample encompasses between 3 and 3000 plants, depending on the way the sensor gun is aimed. As used in this study, each Scheduler index was the average of about ~~50~~ 10-15 plants. (A minimum of 12 Scheduler samples per plot was made). ~~By contrast, representing~~ By contrast leaves from only ~~4 plots~~ 4 plants per plot were sampled with the pressure chamber.

move to top of page (2)

~~This~~ Increasing the number of ~~leaf water potential~~ pressure chamber readings beyond 4 or 5 was not feasible due to the length of time needed per sample. The most ~~re~~ accurate interpretation of these results comes by examining the averages (Table 4). ~~It is interesting to note that~~

These results show that the highest yields were obtained on the plots which were the cool~~est~~ during July and most of August (index readings between 0-3). ~~The taller~~ But, ~~in late August, then~~ ~~highest yielding plots~~ became ~~the~~ somewhat hotter during late August (index reading of 4-6). ~~hottest~~ ~~hotter than the low yielding plots~~. This trend was identical for the pressure chamber readings.

This experiment did not examine the stress states of cotton plants during May and June. Preliminary indications from 1987 are that stress index readings of 4-5 are normal in healthy plants during this period.

Conclusions

1. The Scheduler and pressure chamber have ~~identical~~ very similar response patterns between plots which differed in yields (Tables 1-4).

2) ~~A single~~ Recommended stress index ~~number~~ reading ~~or~~ and pressure chamber values ~~is a~~ dependent on ~~the~~ crop physiology change throughout ~~the~~ season, based on crop development. ~~inconsistent with which to~~ the ~~Schedule~~ irrigations. Seasonal trends must be known for either technique.

3) The rapid ~~large~~ data gathering capacity of the Scheduler ~~provides~~ ~~makes~~ ~~it a~~ gives it a practical advantage over pressure chamber readings. Thousands of plants can be sampled with the Scheduler in the time required to measure the pressure potential of a single leaf.

4 ~~3~~ ~~2~~) The Scheduler ~~is a~~ is a viable tool for observing plant stress in cotton.

~~4) The Statistical analysis of~~

5) These results are consistent with four ~~three~~ independent USDA studies and one independent Univ of California study (Figures 1-4).

Data for plots with
Table 1. Cotton lint yields ranging
between 2.0 and 2.5 bales/Acre.
~~Data~~ Fresno, 1986.

Date	Scheduled Index Range (Min — Max)	Pressure chamber Range (bars) (Min & Max)
July 8	7.1 & 7.7	21.3 & 24.4
July 18	2.4 & 2.5	.
July 21	~~1.4~~ 1.4 & 2.5	14.6 & 15.0
July 24	0.5 & 1.5	12.0 & 13.5
July 29	2.3 & 2.6	15.9 & 17.1
August 1	2.4 & 2.5	15.8 & 17.8
August 8	−0.8 & 0.0	.
August 15	−0.4 & −0.3	.
August 19	0.4 & 1.2	14.5 & 17.5
August 22	2.3 & 3.0	.
August 29	4.5 & 5.1	18.0 & 21.2

Table 2. Data for cotton plots with lint yields ranging between 2.5 and 3.0 bales/acre. Fresno, 1986.

Date	Scheduler Index Range (Min – Max)	Chamber Pressure Range (bars) (min & Max)
July 8	0.3 – 6.8	14.9 & 24.5
July 18	2.0 & 3.8	22.8 & 22.8
July 21	1.4 & 3.2	13.0 & 14.5
July 24	−0.8 & 2.2	12.2 & 14.0
July 29	1.2 & 4.9	15.8 & 19.9
August 1	1.7 & 3.4	16.5 & 20.5
August 5	2.9 & 7.7	19.0 & 24.5
August 8	0.0 & 0.7	.
August 15	−0.5 & 1.5	.
August 19	−0.9 & 2.0	13.0 & 21.3
August 22	1.4 & 6.6	.
August 29	3.5 & 8.2	19.5 & 22.0

Table 3. Data for cotton plots with lint yields ranging between 3.0 and 3.5 bales/acre. Fresno, 1986.

Date	Scheduler Range (min – max)	Chamber Pressure Range (bars) (Min – Max)
July 8	−0.4 – 6.3	13.3 – 25.0
July 18	−2.2 – 4.1	17.5 – 21.8
July 21	0.8 – 2.6	13.3 – 19.5
July 24	−2.2 – 1.6	11.5 – 19.0
July 29	−0.4 – 6.5	15.8 – 22.4
August 1	−0.3 – 2.6	17.0 – 20.0
August 5	1.0 – 7.2	14.4 – 24.7
August 8	−0.8 – 3.7	16.1 – 19.0
August 15	−0.3 – 0.9	.
August 19	−0.7 – 2.7	12.8 – 18.0
August 22	1.6 – 5.2	.
August 29	4.3 – 7.4	16.8 – 25.3

note: Statistical analysis of the ~~variation in~~ sampling variation in Scheduler and pressure chamber readings show that a minimum of 5400 plants per field should be sampled with the Scheduler or 120 pressure chamber readings per field. 5400 plants can be sampled with the Scheduler in 2-3 seconds.

Table 4. Average data for ~~cotton~~ Scheduler and pressure chamber ~~result~~ on plots with three yield ranges. Fresno, 1986.

Date	2.0 - 2.5 bales/acre		2.5 - 3.0 bales/acre		3.0 - 3.5 bales/acre	
	Scheduler	Pressure chamber	Scheduler	Pressure chamber	Scheduler	Pressure chamber
July 8	7.4	22.9	5.1	19.6	3.3	18.9
July ~~23~~ 18	2.5	•	2.8	22.7	3.3	19.6
July ~~23~~ 21	1.9	14.8	1.9	13.8	1.5	16.4
July 24	1.0	12.8	1.2	13.0	-0.7	14.6
July 29	2.5	16.5	3.1	17.4	2.7	15.8
August 1	2.5	16.8	2.4	17.9	1.5	17.0
August 5	5.0	21.5	5.3	21.5	3.8	19.3
August 8	-0.4	•	0.3	•	1.0	•
August 15	-0.3	•	0.7	•	0.3	•
August 19	0.8	16.0	1.0	15.6	0.8	15.4
August 22	2.7	•	3.8	•	3.9	•
August 29	4.8	19.6	5.3	20.7	5.9	21.8

~~Note: Stabil~~

Derivation of The Jackson Equation

by Bronson Gardner

$R_N = \cancel{G} + H + \lambda E$

$H = \rho c_p [T_c - T_A] / r_a$

$\lambda E = \rho c_p [e_c^* - e_A] / [\gamma (r_c + r_a)]$

eliminate e_c^*

$$[e_c^* - e_a] = [e_a^* - e_a] + \Delta [T_c - T_A]$$

Δ = slope of $[e_c^* - e_a^*]$ vs $[T_c - T_A]$ relation

1) $\therefore R_N = \dfrac{\rho c_p [T_c - T_A]}{r_a} + \dfrac{\rho c_p [e_a^* - e_a + \Delta (T_c - T_A)]}{\gamma (r_c + r_a)}$

2) $R_N = \dfrac{\rho c_p [T_c - T_A]}{r_a} + \dfrac{\rho c_p (e_a^* - e_a)}{\gamma (r_c + r_a)} + \dfrac{\Delta (T_c - T_A) \rho c_p}{\gamma (r_c + r_a)}$

3) $R_N = \dfrac{\rho c_p [T_c - T_A]}{r_a} + \dfrac{\rho c_p \Delta (T_c - T_A)}{\gamma (r_c + r_a)} + \dfrac{\rho c_p (e_a^* - e_a)}{\gamma (r_c + r_a)}$

4) $R_N - \dfrac{\rho c_p (e_a^* - e_a)}{\gamma (r_c + r_a)} = [T_c - T_A] \left[\dfrac{\rho c_p}{r_a} + \dfrac{\Delta \rho c_p}{\gamma (r_c + r_a)} \right]$

5) $R_N - \dfrac{\rho c_p (e_a^* - e_a)}{\gamma (r_c + r_a)} = [T_c - T_A] \left(\dfrac{\rho c_p \gamma (r_c + r_a)}{\gamma r_a (r_c + r_a)} + \dfrac{\Delta r_a \rho c_p}{r_a \gamma (r_c + r_a)} \right)$

$\cancel{\lambda}$.

for γ, use g for λ, use L

for Δ, use $\cancel{s}$ S

for ρ, use d

6) $$R_N - \frac{\rho c_p (e_a^* - e_a)}{\gamma (r_c + r_a)} = (T_c - T_a)\left[\frac{(\rho c_p \gamma (r_c + r_a) + \rho c_p \Delta r_a)}{\gamma r_a (r_c + r_a)}\right]$$

7) $$\frac{R_N \gamma r_a (r_c + r_a)}{\rho c_p \gamma (r_a + r_c) + \rho c_p \Delta r_a} - \frac{\rho c_p (e_a^* - e_a) \gamma r_a (r_c + r_a)}{\gamma (r_a + r_a)\left[\rho c_p \gamma (r_c + r_a) + \Delta \rho c_p r_a\right]} = T_c - T_A$$

$\therefore$

8) $$\frac{R_N \gamma r_a (r_c + r_a)}{\rho c_p \gamma (r_a + r_c) + \Delta \rho c_p r_a} - \frac{\rho c_p (e_a^* - e_a) r_a}{\rho c_p \gamma (r_c + r_a) + \Delta \rho c_p r_a} = T_c - T_A$$

divide by $\frac{1/r_a}{1/r_a}$

9) $$\frac{R_N \gamma r_a \left(\frac{r_c}{r_a} + 1\right)}{\rho c_p \gamma \left(1 + \frac{r_c}{r_a}\right) + \Delta \rho c_p} - \frac{\rho c_p (e_a^* - e_a)}{\rho c_p \gamma \left(\frac{r_c + 1}{r_a}\right) + \Delta \rho c_p r_a} = T_c - T_A$$

$\therefore$

10) $$\boxed{\frac{R_N \gamma r_a \left(\frac{r_c}{r_a} + 1\right)}{\rho c_p \left[\gamma \left(1 + \frac{r_c}{r_a}\right) + \Delta\right]} - \frac{e_a^* - e_a}{\gamma \left(1 + \frac{r_c}{r_a}\right) + \Delta} = T_c - T_A}$$

JACKSON, R.D. 1982 CANOPY Temperature and Crop Water Stress. IN: ADVANCES IN IRRIGATION D. HILLEL (ed.) ACADEMIC PRESS

divide by $1/r_c$

$$\frac{R_N \gamma r_a \left(\frac{1}{r_a} + \frac{1}{r_c}\right)}{\rho c_p \left[\gamma\left(\frac{1}{r_c} + \frac{1}{r_a} + \frac{\Delta}{r_c}\right)\right.} - \frac{(e_a^* - e_a)\left(\frac{1}{r_c}\right)}{\gamma\left(\frac{1}{r_c} + \frac{1}{r_a}\right) + \frac{\Delta}{r_c}} = T_c - T_A$$

$$\bigstar \quad = \frac{R_N \gamma \left(1 + \frac{r_a}{r_c}\right)}{\rho c_p \left[\gamma\left(\frac{1}{r_c} + \frac{1}{r_a} + \frac{\Delta}{r_c}\right)\right]} - \frac{(e_a^* - e_a) \cdot 1/r_c}{\gamma\left(\frac{1}{r_c} + \frac{1}{r_a}\right) + \frac{\Delta}{r_c}} = T_c - T_A$$

upper limit ($r_c \to \infty$)

$$\frac{R_N \gamma \left(1 + \frac{r_a}{r_c}\right)}{\rho c_p \gamma \left(\frac{1}{r_a}\right)} = \frac{e_a^* - e_a}{\frac{\Delta}{r_a}}$$

$$= \frac{R_N r_a}{\rho c_p}$$

definitions

ρ = density of air = 1.29 kg/m^3

Δ = Slope of the Saturated of Vapor pressure Relation

B. Gardner Approach

$$R_N = G + H + LE$$

$$H = \rho c_p [T_c - T_A] / r_a$$

$$\lambda E = \rho c_p [e_c^* - e_a] / [\gamma (r_a + r_a)]$$

$G \approx 0.1 R_N$ for Crops

Definitions (continued)

c_p = 1003.2 J/kg °C

γ = psychrometric constant = 0.066 kPa/°C

L = latent heat of vaporization = 2340 J/g

R_N = net radiation (W/m^2)

H = sensible heat flux (W/m^2)

LE = latent heat flux (W/m^2)

G = soil heat flux (W/m^2)

Major Research Questions for a given Crop

- Are the agronomic consequences of water stress understood? Does a sufficient range in TC's exist to make an ~~baseline~~ index possible?
- Have economic returns on controlling stress via the Scheduler been demonstrated?
- ~~Are~~ Have the desired management objectives for using the Scheduler been defined and demonstrated to be effective?
- Is data available which shows a seasonal pattern of optimum and less than optimum index values?
- Is an experiment in progress or being planned for this crop?
- How many locations has this baseline been evaluated in? How many crop cycles?
- Does this crop grow in more than one region or climatic regime? If so, has the baseline been evaluated in each region?
- How trustworthy are baselines from diurnal data?

- What standards are available for quantifying the effects of various stress levels, i.e., to compare with Scheduler readings?

upper baseline

(1) $R_N = H + \lambda E$

$$R_N = \frac{\rho c_p (T_c - T_a)}{r_a} + \lambda E$$

for upper baseline, $\lambda E = 0$

$\therefore R_N \cong$ constant

$\therefore R_N = K_1 + \lambda E$

$$\therefore R_N = K_1 + \frac{\rho c_p (e_c^* - e_a)}{\lambda (r_a + r_c)}$$

$$\therefore \frac{(R_N - K_1)(\lambda)(r_a + r_c)}{\rho c_p} = e_c^* - e_a$$

the left hand side is approximately constant under survey skies

$\therefore$

$$K_2 = e_c^* - e_a$$

$$\therefore \boxed{e_c^* = K_2 + e_a}$$

multiply by -1 and add e_s

$$\therefore e_s - e_c^* = e_s - e_a + K_3$$

$$\therefore (e_s - e_c^*) = VPD + K_3$$

$$\therefore \boxed{(e_s - e_c^*) + K_4 = VPD}$$

Successful Index Criteria

- The agronomic consequences of water stress are understood. Is the effect loss in yield or quality
- Water stress results in a Range of canopy temperature values which is at least 5°C between the upper & lower limits in the region (or time of year) where market potential is high.
- The desired management objectives, in terms of stress, are understood. What is being managed, yield or quality?
- Standards are available for quantifying the effects of water stress. These standards serve as calibration points for the Scheduler. They are generally accurate, but cumbersome or ineffacient to use.
- The index has been evaluated on at least two complete crop cycles. The first to establish a preliminary baseline. The second, to confirm the baseline, & make modifications and demonstrate the ability of a manager to successfully use the index. This provides the season-long index trends which managers often desire. A Range of yields and quality are experimentally produced which are consistent with Scheduler readings.

Technical Problems with CWSI

(1) wet bulb/ dry bulb can be wrong
   a. what is the equilibration time for wet bulb after wetting the wick? (what was the temperature of the water, air temp + VPD?)
   b. How do I know I didn't run it too long before making the reading?
   c. ~~How~~ what ~~do~~ errors occur because I use tap water versus distilled water?
   d. what is the best time constant for TA?

(2) What is the correct aiming procedure? At any given crop stage, I always have an option as to viewing angle, sample frequency + azimuth direction. Depending on the combinations I choose, I will get different average canopy temp's.
   a. The best "average" canopy temp may be the worst one to use for an index, since differences between stressed & non-stressed plants don't occur in all azimuth directions. (Keep the sun at your back
   b. How far out? Where's the sun?
   c. photos are needed

(Sky Radiation)

(3) What is B^* — Can't easily measure this is known to offset IR reading.

(4) What is Tree canopy emissivity? Never do we know this. Becomes even more important to know if an attempt at B^* is made.

(5) What is my blackbody Standard? It has been demonstrated that among blackbodies that are "traceable to NBS standards" that a significant variation in energy output may exist at the same indicated temperature. The effect would be variations in indicated IR reading of 0.5°C - 1.0°C. This means a given manufacturer using an NBS blackbody can be expected to produced uniformly responding instruments, but that one manufacturer may differ slightly from another that is also producing uniformly responding instruments.

(due to subtle differences in emissivities)

- How accurate to display numbers? 0.28 to 0.42 2.6 to 4.4 Can be produced with measurement errors. Not as bad if you get a 3 or a 4.

(6) The correct scale of the empirical approach is not 0-10 (or 0-1) By definition, 50% of the time the index will be negative.

(7) The 0-1 scale is too hard for the average user to learn to discuss / interpret. Most people are very comfortable with 0-10. A few are comfortable with 0-100%

(8) Differences ~~among~~ in index values among instruments which are all "in spec" & Thus, each package is ~~a little~~ somewhat unique. Cannot expect two packages to yield exactly the same numbers.

(9) ~~Baseline~~ Upper baseline -- Value need to be selected with two purposes: 1) calculating realistic values 2) insuring reasonable index stability even at low VPD values.

- What is the "natural variability of T_A? (~ 5°F at 1M above surface)

(10) Extrapolation of intercepts back to the origin at 0 VPD, when no data was taken ~~in~~ in this region. Statistical theory says extrapolation outside the range of a data set is dangerous. Observation confirm this for CWSI baselines.

(11) ~~Selected~~ Baseline selection philosophy

a. Approach #1 is to continually re-define baselines for stage of growth and variety. We feel this approach keeps the ~~users~~ growers in a state of confusion, since they interpret this continual redefining ~~of~~ as uncertainty in the technology. They therefore become reluctant to start using an index which they think must change next year.

b. Approach #2 is to define a "Standard baseline", ~~and~~ never changing it after defining it (unless it is very ~~to~~ wrong). Interpretation

(11) are then based on "expected values" for a given stage of growth or variety. ~~This~~ Growers view this as a simple calibration, requiring only a chart or a graph to adapt the "standard index" to their situation. This is the best marketing approach. Users don't care if the "expected value" early in the season is a 4 or 5 or that it may change to a 6 or 7 later in the season. They just want to know the pattern to expect.

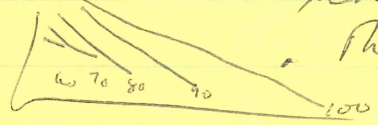
(12) What is the sensitivity of ~~as~~ given baseline to measurement / sampling / equilibration errors? Are there potential problems serious enough to negate the technique?

(13) ~~What is the "0~~

The optimum $CWSI$ value is not always zero. Maximum Transpiration ($CWSI$) = Luxury consumption in many cases. In grapes, the grape quality can be reduced by excessive transpiration.

Challenges to CWSI Research

1. Develop a "standardized baseline" for each crop that has the right general response and an upper limit set high enough to prevent serious sensitivity problems

2. Investigate the effect of air temperature changes on the baseline. At any given TA, the maximum VPD is different 

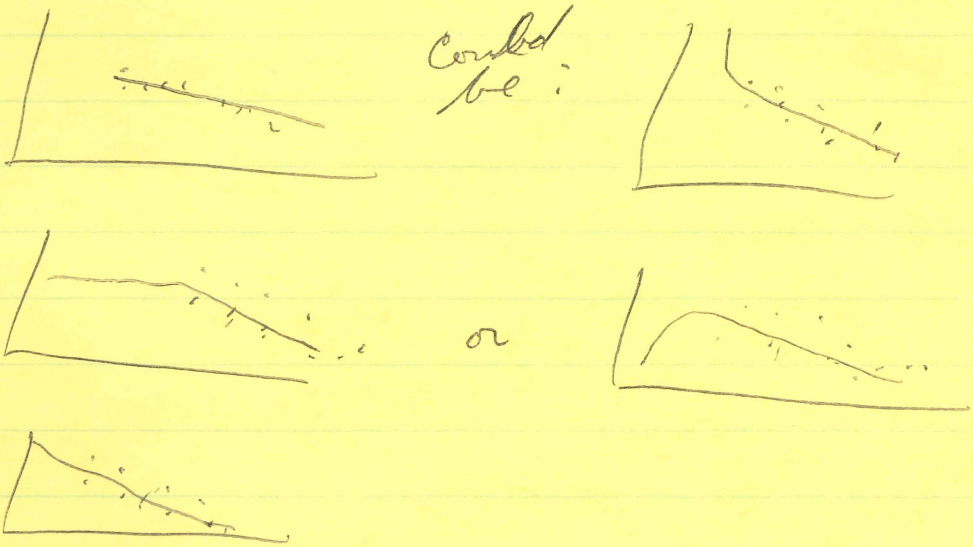
. The implications for regression

3. Develop interpretation curves (~~plots~~ CWSI vs. time, showing the expected pattern of CWSI for a given variety, at different yield levels. Print photos showing the correct aiming technique

4. Investigate uses for CWSI other than irrigation scheduling -- this is the exciting area.

5. Once the "standard baseline" and calculation procedures are defined, these should not be changed. This is need for market perception that technical confidence is high.

6. Do not extrapolate the behavior of CWSI outside the range of data. Do not assume linearity.



7. Is the problem at low VPD's caused by a problem with the plants or a problem with the current definition of the index (for which very little data is available)

8. Identify the best management practices for crops using CWSI. Maintaining the lowest index isn't always the desirable.

9. CWSI isn't a stress indicator but an ET indicator. Stress implies something bad. ~~ET bad~~ High CWSI values aren't always bad.

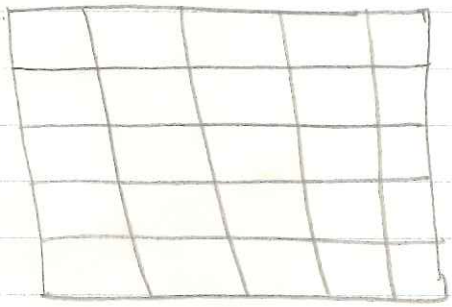
10. ~~Often~~ Detail the anomalies which occur using CWSI. For example, CWSI goes up in saturated soils (after rain or irrigation). This is a normal response, not indicating water stress, but reduced ET due to oxygen deficiency. Growers ~~do~~ tend to interpret readings narrowly unless educated otherwise.

11. Mis-representation ~~of~~ of the concept or lack of grower comprehension. Great care must be taken not to promote growers too much. ~~So~~ ~~to~~ That is why the effort educational effort on the practicalities of the technique. CWSI as an ET rate indicator presents fewer conceptual problems than CWSI as a stress indicator. ~~The~~ "stress" is ~~the~~ the. Growers expect the sellers of CWSI to be able to give them a definitive answer to physiological questions and offer concrete advice on how to ~~to~~ use this on

12. Develop a theory which incorporates absolute T_c. This is critical to the evolution of IR and the effective management of plants -- CWSI doesn't tell the whole temperature-related story.

Theory of the use of average temperatures and standard deviations in estimating stress.

To illustrate, suppose a field is divided into a grid containing 25 squares:



we now use an infrared thermometer to measure the average temperature of each square. We then calculate the average temperature of the entire grid ($\bar{T}$) from these 25 measurements. Next, let's subtract a reference temperature ($\bar{T}$) from each individual measurement and record the results:

0	0.5	0	0.9	1.0
0	0	2.0	0.1	0
0	0.7	0	0	0
0.2	0	1.5	0	0
0	0	0	0	0

Case 1 (stress monitoring case)

If a positive number indicates stress, we see that 8 squares are exhibiting various levels of stress. How, then, shall we compute the average stress condition? If we simply average the stress over the entire 25 squares (as would be done on a non-irrigated field) we see that $\Delta\bar{T} = 0.28° \pm 0.54$ On the average, then, the entire square is only

0.28 degrees above $\bar{T}$. But, is this actually a fair indication of the stress level? Does the field need irrigating?

If we take the average of only those squares which are above $\bar{T}$, we see that $\Delta\bar{T} = 0.86 \pm 0.64$, significantly higher than before. (although the standard deviation was not greatly affected).

If we multiply 0.86 by $\frac{8}{25}$ (the percentage of squares with stress) we obtain a $\Delta\bar{T}$ of 0.28. In other words, our first calculation was weighted for the <u>percentage of area</u> in the field which was stressed.

Let's examine another field:

1.1	1.5	0	0	1.6
1.2	1.6	1.9	0	1.4
1.7	1.6	1.3	1.9	0
1.4	1.1	0	1.7	0
0	0	0	0	0

case 2 (stress monitoring case)

$\Delta\bar{T}$ (using the 1st method) = 0.84 ± 0.78

ΔT (using the 2nd method) = 1.47 ± 0.27

Summarizing:

ΔT	Case 1	Case 2
1st Method	0.28 ± 0.54	0.84 ± 0.78
2nd Method	0.86 ± 0.64	1.47 ± 0.27

note that the standard deviation of method 2 actually decreased, although the level of stress increased.

Let's examine one more case

5.0	3.5	7.0	1.4	0
2.8	7.2	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

Case 3
(irrigation scheduling case)

$\Delta\bar{T}$ first method = 1.08 ± 2.27
$\Delta\bar{T}$ second method = 4.48 ± 2.33

In practice, we would conclude that a small amt of stress existed on the basis of method one, i.e., on the average, the field does not need irrigating. We know from experience, however, that the portion of the field which is exhibiting the stress must be severely stressed. Hence, <u>that portion</u> of the field needs water. ($\Delta\bar{T}$, second method). (We also see that the standard deviation of the measurements happen to be similar in this case.)

From cases 1 & 2, we see that the standard deviation of the temperature measurements is generally largest when the data from all 25 blocks is used. However $\Delta\bar{T}$ is largest when only the positive values are used. Hence, for decision making,

we must determine which method to base our judgments on. Part of the decision depends on the pattern of stress. If the pattern is randomly distributed throughout the field (cases 1 or 2) then the standard deviation of method 1 or the average of method 2 gives us the most sensitive indicator of stress. If stress develops in a systematic fashion (case 3) then the average of method 2 is the most sensitive indicator of stress.

The above analysis suggests that the percentage of a field experiencing stress, as well as the average ΔT, may be useful in scheduling irrigation. Suppose in case three that the square that exhibits a 1.4 °C stress is used as a reference point. When that square becomes 1.4 °C warmer than average, we know that 6/25 of the field is experiencing some kind of stress (from moderate to severe.) On the other hand, if the square exhibiting 7.2 C is used as the reference point, we could irrigate when that square reaches, say, a $\Delta \bar{T}$ of 1.0 C. We would then be confident that only 1/25 of the field was actually experiencing stress. The problem, then, is to identify the pattern of stress development in a field.

Dear :

MANY AS
~~Totain~~ herbicides don't ~~always~~ work ~~as~~ well.
Why? Often ~~the~~ REASON is simple : ~~water~~ The
weeds ~~suffer~~ from water stress, This MEN

MANY herbicides don't always work as well
as they should. Why? Often the reason
is simple : The weeds aren't healthy
enough to absorb the herbicide effectively.
~~Weeds~~ The weeds are water-stressed.
~~The Solution~~ For example, The Herbicide
HANDBOOK (1983), states that ~~TENORAN~~
chlorotoluron (~~a Ciba-Geigy product~~ a post emergent herbicide) will work "with
no geographical limitations where sufficient
moisture is available for growing crops" and
that the transpiration rate of the weed
controls the ~~rate~~ Movement of ~~it~~ ~~TENORAN~~ Chlorotoluron
~~from roots to LEAVES~~ (and therefore,
its effectiveness), ~~Herbicides applied to stressed~~
weeds ~~will~~ may be ~~less effective~~ than expected. later

~~The problem is paradoxical. Weeds must be~~
~~healthy to be killed.~~ & ~~rapidly growing~~
~~The Solution to this problem~~ use has several
options : . determine the

Roles the Scheduler CAN play in Chemical Applications

1. Directly Assessing the stress status of weeds
2. Indirectly assessing weed stress status by
   - ~~Measuring crop stress~~
   - Measuring soil evaporation rates and surface temperature to infer the stress status of small, shallow rooted weeds

Since the effectiveness of many folior herbicide is dependent on the stress status of the weeds (Dow chemical, Reference), the Right rate, the first time could ~~can~~ be applied with confidence, every time. If only the stress status of the weeds could be determined.

~~Post - Emergent~~ Herbicides
The Schedules May Be Useful ON

Pg.			FACTOR	
~~3~~	~~Acifluoren (Sreelost)~~	~~CRR~~	~~10~~	Question: Is the Activity
19	Amitrole	~~CRR~~	5	of a herbicide Affected
~~22~~	~~AMS~~		6	by Soil Temp's at the
27	ASULAM	~~CRR~~	4	time of Application?
35	BarbAN		4	
37	Sethoxydim		10	CRR = Rates can vary by
40	BenaZolin		2.5	a factor of 10.
50	Bentazon		3	Most Rates vary by factor
~~54~~	~~Bfenox~~		~~1.5~~	of 2 to 4
71	Bromoxynil		2	
78	Buthidazole	~~CRR for~~	10 ~~industrial uses~~	
95	chlorFlurenol		1.5	
~~98~~	~~chlorfenprop~~	Prel~~Fest~~	~~Related to stress status of crops~~	
~~101~~	~~chlorpropham~~		~~3~~	
107	chlorsulfuron		2.5	
128	2,4-D	~~Large Range in rate~~	9	(2RR)
135	Dalapon	~~high Large range in rates~~	20	
141	2,4-DB	CRR	10	
146	DesMedipham		2	FACTOR
151	Dicamba		20	= MAX rate
164	3,6-Dichloropicolinic Acid		16	Min Rate
~~239~~	~~Fluometuron~~		~~5~~	
244	~~Flo~~ Flurenol		2	
259	Glyphosate		2-4	
263	Glyphosine		2	

Pg	Herbicide	% Range in application (divide by 100)	Key Phrases on Chemical Behavior
19	Amitrole	5	absorbed slowly
27	ASULAM	4	readily Absorbed
35	BARBAN	4	Adsorbed
37	Sethoxydim	10	Adsorbed Rapidly
40	BENAZOLIN	2.5	
50	Bentazon	3	Effective after foliar absorption
71	Bromoxynil	2	
95	Chlorfluronol	1.5	Penetrates Readily via foliage
107	Chlorsulfuron	2.5	

Page	Herbicide	Factor
293	MCPA	9
295	MCPB	3
297	MecoPROP	1.5
322	MH, Maleic Hydrazide	☆ 2
376	PhenMediphan	1
429	Silvex	2
443	2,4,5-T	6

Key Phrases:

Glenn:

These notes are sloppy & incomplete, but there may be some useful information

- Bronson

Memo: A. Ahnell

re: Environmental Short Course

from: B. Gardner

Are funds available ~~for~~ ~~it~~ to allow me to attend ~~one~~ an Environmental Regulation Course? I believe my ability to serve on PERF and Global Warming committees would be enhanced if I could receive this type of training.

Draft .. Internal Use Only

A note on a new technique for evaluating aerodynamic resistances

In the absence of ~~direct~~ solar radiation, radiative heat ~~losses~~ flows from a surface must balance the conductive and convective heat flows into a surface:

$$h(T_a - T_c) = \sigma\left[(T_c + 273.1)^4 - (T_s + 273.1)^4\right] \quad (1)$$

~~$h(T_a - T_c) = \sigma(T_c^4 - T_s^4)$~~

where h = convective heat transfer coefficient

$$r_a = \frac{\rho c_p}{h}$$

r_a = aerodynamic resistance (sec/m)

T_c = surface temperature in the absence of radiation (°c)

T_a = ambient air temperature (°c)

T_s = effective sky temperature (°c)

σ = Stephan-Boltzmann Constant

Inspection of equation 1 shows that all components can be directly measured except h. It is therefore possible to directly measure h. During the daytime, it would be necessary to ~~th~~ measure the temperature of a shaded surface instead of one exposed to direct sunlight.

~~Ca~~ Ra is modeled in figure 1. The results show that Ra can be expected to range between 5 and 150 sec/m for well watered plants. ~~Ra Ca~~ Ra increases as sky temperature increases and decreases as the difference ~~in temperature~~ between ~~air~~ ambient air and non-irradiated surface temperature decreases. This difference will always be positive.

Calculating LE using r_a

The energy balance of a crop is (ignoring soil heat flux)

$$R_N = LE + H$$

if r_a is directly measured, as described and R_N is directly measured,

$$LE = R_N - H$$
$$= R_N - h(T_a - T_c)$$

$$= R_N - \frac{\rho c_p (T_c - T_a)}{r_a}$$

$$LE = R_N - \frac{\rho c_p (T_c - T_a)}{r_a}$$

$$LE = R_N - \frac{1200 (T_c - T_a)}{r_a} \qquad (2)$$

~~This is~~

Directly measuring r_a makes it theoretically ~~technically~~ possible to directly measure the LE rate of a crop without the use of any crop coefficients or "fudge" factors, which take a long time to develop and are always

subject to question of accuracy and applicability. ~~The theory~~ The theory is sound, but ~~needs~~ should be evaluated.

Calculating CWSI using r_a

Theoretically, CWSI is:

$$CWSI = \left(1 - \frac{ET}{ET_p}\right)$$

If R_N is either estimated or measured, ET_p can be estimated as:

$$ET_p = R_N - \frac{\rho c_p \left(\left[(T_{sh} + D) - T_a \right] \right)}{r_a}$$

~~r_a is difficult~~

T_{sh} = shaded crop Temp

D = difference between shaded crop temp and well watered crop Temp. This would need to be measured

for a given crop and may be a function of R_N. Experience has shown that 5°C is about right for Turf grass.

$$\Theta T = R_N - \frac{\rho c_p (T_c - T_a)}{r_a}$$

T_c = actual crop temp

Thus,

$$1 - CWSI = \frac{R_N - \frac{\rho c_p (T_{sh+D} - T_a)}{r_a}}{R_N - \rho c_p (T_c -}$$

$$1 - CWSI = \frac{R_N - \frac{\rho c_p (T_c - T_a)}{r_a}}{R_N - \frac{\rho c_p (T_{sh+D} - T_a)}{r_a}}$$

Thus

$$\therefore \quad 1 - CWSI = \frac{R_N r_a - \rho c_p (T_c - T_a)}{R_N r_a - \rho c_p (T_{sh+D} - T_a)}$$

$$= \frac{\frac{R_N r_a}{\rho c_p} - (T_c - T_a)}{R_N r_a / \rho c_p - \text{min}}$$

$$1 - \cos\varepsilon = \frac{\frac{R_N r_a}{\rho c_p} - (T_c - T_a)}{\frac{R_N r_a}{\rho c_p} - (T_{sh+D} - T_a)}$$

Thus,

$$\cos\varepsilon = 1 - \left[\frac{\frac{R_N r_a}{\rho c_p} - (T_c - T_a)}{\frac{R_N r_a}{\rho c_p} - (T_{sh+D} - T_a)} \right]$$

Calculating CWSI — the intercept

if VPD = 0

$$T_c - T_a = \text{intercept} = \frac{r_a R_N}{\rho c_p} \cdot \frac{\gamma (1 + r_c/r_a)}{\Delta + \gamma (1 + r_c/r_a)}$$

$$T_c - T_a = \frac{r_a R_N}{\rho c_p} \cdot \frac{\gamma}{\frac{\Delta}{1 + \frac{r_c}{r_a}} + \gamma}$$

$$\therefore \quad \boxed{T_c - T_a = \frac{r_a R_N}{\rho c_p} \cdot \frac{1}{\frac{\Delta}{1 + \gamma \frac{r_c}{r_a}} + 1} = \text{intercept}}$$

if $\frac{r_c}{r_a} \approx 1$, for the well watered case

$$\boxed{\text{intercept} = \frac{r_a R_N}{\rho c_p} \cdot \frac{1}{\frac{\Delta}{1+\gamma} + 1}}$$

from Jackson

$$\frac{r_c}{r_a} = \frac{\frac{\gamma r_a R_N}{\rho c_p} - (T_c - T_a)(\Delta + \gamma) - VPD}{\gamma \left[(T_c - T_a) - \frac{r_a R_N}{\rho c_p} \right]}$$

from Jackson

$$\frac{r_c}{r_a} = \frac{\frac{\gamma r_a R_N}{\rho c_p} - (T_c - \bar{T}_a)(\Delta + \gamma) - VPD}{\gamma\left[(T_c - \bar{T}_a) - \frac{r_a R_N}{\rho c_p}\right]}$$

$\gamma = 0.066$

$\rho c_p = 1200$

$\Delta =$ kPa

$VPD =$ kPa

$R_N = W/m^2$

Calculating the Slope

$$\text{slope} = \frac{-\ 1}{\Delta + \gamma\left(\frac{r_c}{r_a}\right)}$$

Calculating the upper limit

$$\Delta T_{max} = \frac{r_a R_N}{\rho c_p}$$

$$\text{Slope} = \frac{1}{\Delta + \gamma\left(\frac{r_c}{r_a}\right)}$$

Slope

$(T_A + T_a)/2$	$\frac{r_c}{r_a}$ 0.5	1.0	2.0	4.0	8.0	16.0	32.0
10	5.5	4.7	3.6	2.4	1.5	0.83 0.88	0.44
20	4.1	3.6	2.9	2.1	1.4	0.79 0.8	0.43
30	2.9	2.7	2.2	1.7	1.2	0.73 0.7	0.41
40	2.0	1.9	1.7	1.4	1.0	0.66	0.39
50	1.4	1.3	1.2	1.1	0.8	0.58	0.36

$(T_A + T_a)/2$	50	100	r_c/r_a 200	300	400
10	0.29	0.15	0.07	0.05	0.04
20	0.28	0.15	0.07	0.05	0.04
30	0.28	0.14	0.07	0.05	0.04
40	0.27	0.14	0.07	0.05	0.04
50	0.25	0.14	0.07	0.05	0.04

$(T_R + T_A)/2$	r_c/r_a 2	2.5	3.0	3.5	4.0	4.5	5.0	6.0	7.0
10	3.6	3.2	2.9	2.6	2.4	2.2	2.1	1.8	1.6
20	2.9	2.7	2.4	2.3	2.1	2.0	1.8	1.6	1.5
30	2.2	2.1	2.0	1.8	1.7	1.6	1.6	1.4	1.3
40	1.7	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.1
50	1.2	1.2	1.1	1.1	1.1	1.0	1.0	0.9	0.9

Energy Balance

$R_N \cong H + LE$

R_N = energy available for $H + LE$

$R_{SW\,BAL} + R_{LW\,BAL} = H + LE$

H = heating the air

LE = evaporating water

$R_S(1-r) + \varepsilon_a \sigma T_a^4 - \varepsilon_c \sigma T_c^4 = H + LE$

r = reflectivity of the crop

$$H = \rho c_p (T_c - T_a)/r_a$$

$$LE = \frac{\rho c_p}{\gamma} \frac{(e_s(T_c) - e_a)}{r_a + r_c} = \frac{\rho c_p}{\gamma} \frac{(e_{ss} - e_a)}{r_a + r_c}$$

$$\therefore R_S(1-r) + \varepsilon_a \sigma T_a^4 - \varepsilon_c \sigma T_c^4 = \rho c_p \frac{(T_c - T_a)}{r_a} + \frac{\rho c_p}{\gamma} \frac{(e_{ss} - e_a)}{r_a + r_c}$$

let $r_a + r_c = r_v$

$r_h = r_a$

$$\therefore \underbrace{R_S(1-r) + \varepsilon_a \sigma T_a^4 - \varepsilon_c \sigma T_c^4}_{\text{available energy}} = \underbrace{\rho c_p \frac{(T_c - T_a)}{r_h} + \frac{\rho c_p (e_{ss} - e_a)}{\gamma \; r_v}}_{\text{partitioning}}$$

the ratio of $\frac{H}{LE}$ is:

$$\frac{\rho c_p (T_c - T_a)}{r_h} \cdot \frac{\gamma r_v}{\rho c_p (e_{ss} - e_a)}$$

if $r_v \approx r_a$

then

$$\frac{H}{LE} = \frac{(T_c - T_a)\gamma}{(e_{ss} - e_a)}$$

Equations for Use in Irrigation Scheduling

(1) $SDD = T_c - T_a$ (Idso et. al. 1977)

where T_c = crop temperature

T_a = air temperature above the canopy

$\overline{SDD}$ is calculated for several locations with a "uniformly irrigated" field. If a discontinuity in the field exists, i.e., a "wet" and "dry" side of a center pivot, the $\overline{SDD}$ is calculated for each section. A positive value of SDD <u>always</u> indicates the need for irrigation. Negative SDD's may or may not indicate the need for irrigation.

1(b) $BI = T_c - T_w$

T_w = wet bulb air temperature

1(c) $BZ = 10 - 10 ** (T_c / T_w)$

2) $$WSI = \frac{(T_c - T_a)_{Real} - (T_c - T_a)_{min}}{(T_c - T_a)_{max} - (T_c - T_a)_{min}}$$ (Idso method)

$(T_c - T_a)_{max} \cong 3.0\ ^\circ C$

$(T_c - T_a)_{min} = 2.67 - 0.002059\,VPD$

$$\therefore WSI = \frac{(T_c - T_a)_{Real} - 2.67 + 0.002059\,VPD}{0.33 - 0.002059\,VPD}$$

VPD = vapor pressure deficit (Pa)

Calculate WSI in Arkansas and Nebraska. Irrigate if WSI > 0.3 (Hatfield). In Nebraska, compare WSI for the wet and dry side of the field. High WSI values (>0.2) occur naturally on very small plants.

WSI = 0 = no stress

WSI = 1 = maximum stress

0 = no stress
1 = maximum stress

irrigate at CWSI ≥ 0.3

3) CWSI (Jackson Method)

$$CWSI = \frac{\left(g\left(1 + r_c/r_a\right) - g\left(1 + r_{cp}/r_a\right)\right)}{s + g\left(1 + r_c/r_a\right)}$$

$$r_{cp}/r_a \cong 0.5$$

$$r_c/r_a = \frac{\left[g\, r_a R_N/(d\, c_p)\right] - (T_c - T_a)(s + g) - (e_{sA} - e_a)}{g\left[(T_c - T_a) - r_a R_N/(d\, c_p)\right]}$$

R_N = net Radiation (w/m²)
e_{sa} = saturation vapor pressure at Ta (Pa)
e_a = actual vapor pressure (Pa)
d = density of air ($kg\, m^{-3}$)
c_p = heat capacity of air ($J\, kg^{-1}\, C^{-1}$)
r_a = aerodynamic resistance ($sec\, m^{-1}$)
g = Psychrometric constant (Pa °c)
s = slope of saturation vapor pressure curve (Pa °c)

$$r_a = \frac{4.72\left[4.89\left[(h-d)/z_o\right]\right]^2}{1 + 0.54\, U}$$

U = approximate w/ 5, 10, 15, 20 increments of 0, 5, 10, 15, 20 mph etc.

~~h = canopy height (m)~~
~~d = 0.64h~~
~~z_o = 0.13h~~

U = windspeed (m/sec)

note: mi/hr (0.447) = m/sec
ft (0.3048) = m

4) $TSD = T_N - T_I$

T_N = Temperature of area not irrigated
T_I = Temperature of irrigated area

if $(T_N - T_I)$ exceeds 0.5 °C, then irrigate

this can be used in Nebraska

5) $\sigma(T)$ = standard deviation of canopy temperature

Arkansas

if $\sigma(T)$ exceeds well watered σ (established after an irrigation (2-3 days after)) then irrigate

Nebraska:

if $\sigma(T)_N$ exceeds $\sigma(T)_W$ then irrigate

6) $\sigma(CWSI)$ and $\sigma(WSI)$

$\sigma(T_c - T_a)$

Definitions

input once * R_1 = Net Radiation = 0.79 R_s R = incoming Solar

T_1 = crop Temperature (IRT) (irrigated) (mean)

input once * T_2 = ~~dry~~ dry bulb air Temperature

fixed * D_1 = maximum crop-air Temp = 3°

* D_2 = minimum crop-air Temp = 2.67 - 0.002059 * V1

* V_1 = vapor pressure deficit = $e_1 - e_3$

* e_1 = saturated air vapor pressure (dry bulb) (Pa)

* $e_1 = 610.78 \exp\left(\left(17.269382 * T_2 / (T_2 + 237.30)\right)\right)$

→ e_2 = Saturated vapor pressure (wet bulb) = $610.78 \exp(17.269382 * T3/(T3 + 237.30))$

* e_3 = actual vapor pressure (Pa)

→ * $e_3 = e_2 - g\,(1 + 0.00115 * T3)(T_2 - T_3)$

input once * T_3 = wet bulb air temperature

* $g = 64.54859 + 0.06472303 * T_2$ g = psychrometric Constant (Pa $°C^{-1}$)

* R_2 = relative humidity

→ * $R_2 = 100 (e_3 / e_1)$

* $r_3 = r_{cp}/r_a = 0.5$

* d_3 = air density (kg/m^3)

* $d_3 = 1.287491 - 4.035152 (10^{-3}) * T_2$

* C_1 = Heat Capacity of air = 1006 J/kg

* r_4 = aerodynamic resistance = $4.89/(1 + 0.54 * U2)$

input * U2 = windspeed in m/sec

* U2 = 0.447 * U1

* U1 = estimated windspeed in miles per hour

* S2 = slope of saturation vapor pressure curve (Pa C^{-1})

* $S2 = 44.869255 + 2.83791 * T2 + 0.068165 * T_2^2 + 1.937586 (10^{-3}) * T_2^3$

* T4 = Crop temperature (IRT) (not-irrigated) (mean

S1 = standard deviation of I1 S2 = Std of I2

S3 = standard deviation of I3 S4 = Std of I4

Water Vapor and Air properties

air density ($kg\,m^{-3}$) = d = $1.287491 - 4.035152(10^{-3})T_a$

$d = 1.287491 - 4.035152(10^{-3})T_a$

where T_a = air temperature (°C) (between 0 and 45°C)

air heat capacity = c_p

$c_p = 1006\ J\,kg^{-1}\,°K^{-1}$

dry air saturation vapor pressure (Pa) = e_s

$e_s = 610.78 \exp((17.2693882\,T/(T+237.30)))$

(al Weiss paper)

T = air temperature in °C (dry bulb temperature) (0 TO 100 °C)

slope of saturation Vapor Pressure Curve ($Pa\,°C^{-1}$) = S

$S = 44.869255 + 2.837919T + 0.068165T^2 + 1.937586(10^{-3})T^3$

(From Fritchen & Hay Data)

T = air temp in °C (−9 to 39 °C)

latent heat of vaporization ($J\,g^{-1}$) = L

$L = 2500.89592 - 2.36449\,T_W$

T = wet bulb air temp °C (−9 to 39 °C)

Definitions

$I_1 = T_1 - T_2$

$R_5 = [g * R_4 * R_1 / (d3 * C1)] - I_1 * (S2 + g) - V1$

$R_6 = g * ((I_1 - R4 * R_1) / (d3 * C1))$

$R_7 = R5 / R6$

$R_8 = (g * (1 + R7) - g * (1 + R3))$

$R_9 = S2 + g * (1 + R7)$

$I3 = R8 / R9$

$I2 = (I1 - (2.67 + 2.059E-3 * V1) / (0.33 - 2.059E-3 * V1))$

$I2 = (I1 - D2) / (D1 - D2)$

$I_4 = T_1 - T_3 =$ Crop temp - wet bulb

$I5 = 10 - 10 * (T_C / T_W)$

Z1$ = Date

Z2 = Start Time

Z3 = end Time

Water Vapor and air properties

psychrometric constant ($P_a\ °C^{-1}$) = g

$$g = 64.60148 + 0.062622\,T$$

T = air temperature in °C

$$g = 64.54859 + 0.06472303\,T$$

S/g ratio = $\frac{\Delta}{\gamma}$

$$\frac{S}{g} = 0.693622 + 0.043337T + 1.038446(10^{-3})T^2 + 2.725435(10^{-5})T^3$$

T = air temperature in °C

$$\frac{S}{S+g} = \frac{\Delta}{\Delta+\gamma} \quad \text{ratio}$$

$$\frac{S}{S+g} = 0.409569 + 0.015223T - 3.346094(10^{-5})T^2 - 1.81593(10^{-6})T^3$$

T = air temperature in °C

Actual Pressure (P_a) = e_a

$$e_a = e_w - g\,(1 + .00115\,T_w)(T_d - T_w)$$

T_d = dry bulb temperature

T_w = wet bulb temperature

e_w = saturation vapor pressure at T_w

Actual Vapor Pressure (P_a) deficit = VPD

$$VPD = e_s - e_a$$

ET Calculations

① Water Balance

$$\Delta SW = ET + D - PI \pm RO$$

ΔSW = change in soil water
ET = Evapotranspiration
PI = Precipitation
RO = Run off
D = Deep Drainage

- The model should only be run if D is negligible ∴ after a heavy rain, wait for 1-2 days for the soil to drain. This also allows time for RO to become negligible

Thus, after a few days w/o rain

$$\Delta SW = ET - \cancel{PI}^{0} = ET$$

If a rain exceeds ΔSW, then set $ET = 0$, and wait for the rain to stop. If rain is too large, a waiting period for drainage / Run off is necessary.

ET Models

★ (1) Linacre Model : Requires T_A + RH

$$ET = \frac{\left[\frac{700 \cdot T_m}{100 - \ell}\right] + 15\,(T_A - T_d)}{[\,80 - T_A\,]}$$

$T_m = T_a + 0.006\,z$

T_A = Mean daily temp (°C)

z = elevation (meters)

ℓ = latitude (degrees)

T_d = mean dew-point temp

estimated Accuracy : ± 0.07 inches per day

- No calibration coefficients
- Simple
- very little Literature Evaluation

ET Models

(2) Jensen-Haise

$$ET_p = R_S (0.025 \cdot T_A + 0.08)$$

R_S = Daily Total Radiation in inches of water
T_a = Mean air temp in °C
-- under estimates in advective conditions
- No calibration

(3) Solar Thermal Unit

$$ET_p = 6.1 * 10^{-9} R_S (1.8 T_A + 1)$$

R_S = total solar radiation J/m²
T_A = Mean daily temp (°C) plus 0.55 °C
- No calibration

(4) Slatyer & McILROy

$$ET_{eq} = \left(\frac{\Delta}{\Delta+\gamma}\right)(R_N + S)$$

ET_{eq} = minimum ET possible for the day/hour

R_N = Net radiation
S = soil heat flux
Δ = slope of the saturation vapor pressure curve
γ = psychrometric constant

- No calibration

ET Models

★ (5) Penman Combination #1

$$ET_p = R_N + S - \frac{\rho c_p (T_c - T_a)}{r_a}$$

Accurate under advective + non-advective conditions

r_a = a function of windspeed / crop

(Evaluated by Blad + Verma)

* (theoretically the most accurate)

(6) Penman Combination #2

$$ET_p = \frac{\Delta}{\Delta + \gamma}(R_N + S) + \frac{\rho c_p}{\Delta + \gamma}\left(\frac{VPD}{r_a}\right)$$

r_a = function of windspeed / crop

* Most people ignore S, which could be significant

(7) Penman #3

$$ET_p = f_1 E_0$$

f_1 = 0.8 in summer, 0.6 in winter

$$E_0 = \frac{\Delta R_{N0} + \gamma E_a}{\Delta + \gamma} = \text{Evaporation over open water}$$

$E_a = f(U) \cdot VPD$

$f(U) = 0.27\left(1 + U/100\right)$

R_{N0} = net R_N over open water

U = windrun (Km/day)

ET Models

★ (8) Penman # 4 (Monteith)

$$ET_i = \frac{\Delta(R_N + S) + \frac{\rho c_p \cdot VPD}{r_a}}{(\Delta + \gamma)\left(\frac{r_a + r_c}{r_a}\right)}$$

Now we need r_a (windspeed function) and r_c

(9) Priestley-Taylor

$$ET_p = \alpha \frac{\Delta}{\Delta + \gamma}(R_N + S)$$

α = site specific parameter = 1.26 on the average

★ (10) Monteith Model

$$ET = \frac{\rho c_p}{\gamma}\left(\frac{e_a - e_{ss}}{r_a + r_c}\right)$$

e_a = actual vapor pressure

e_{ss} = saturated vapor pressure at a given T_c

r_a = f(windspeed)

r_c = canopy stress.

ET Models

(11) Penman Combination #5

$$ET_p = \frac{\Delta}{\Delta+\gamma}(R_N + S) + \frac{\gamma}{\Delta+\gamma} f(u)(VPD)$$

$$f(u) = 15.36(1 + 0.00621 * U)$$

U = windspeed in Km/day

R_N = Daily Net radiation

S = total soil heat flux

or

$$f(u) = \frac{\rho c_p}{r_a}$$

Combining ET_p + CWSI

$$\text{Index} = 10\left(1 - \frac{ET}{ET_p}\right)$$

$$\therefore \left[1 - \frac{\text{Index}}{10}\right] = \frac{ET}{ET_p}$$

$$\therefore \quad ET = ET_p\left[1 - \frac{\text{Index}}{10}\right]$$

if Index < 0 then set Index $= 0$
if Index > 10 then set Index $= 10$

Estimating R_N From R_S

Note: There is NO CONSENSUS of opinion
Your guess is as good as mine
∴ Measure R_N or use a different equation

Best estimate of R_N:

$$R_N = 0.77 R_S - \sigma T_c^4 +$$

→ Must be close

R_S = TOTAL INCOMING heat load

Latent heat of water – evaporative energy Conversion

$L = 2450 \frac{\text{Joules}}{\text{gram}}$ (latent heat of Vaporization)

$\rho = \frac{1\ g}{cm^3} = \frac{10^6\ g}{m^3}$

$L = \frac{2450\ \text{Joules}}{cm^3} = \frac{2.45 \times 10^9\ \text{Joules}}{m^3}$

1 Watt = 1 Joule/sec

1 watt/m^2 = $\frac{1\ \text{Joule}}{m^2\ \text{sec}}$ $\therefore$ 1 $\frac{\text{Watt-sec}}{m^2}$ = 1 $\frac{\text{Joule}}{m^2}$

$L = \frac{2.45\ 10^9\ \text{Watt-sec}}{m^3}$

$\frac{W}{m^2} \cdot \frac{m^3}{\text{Watt-sec}} = \frac{m}{\text{Sec}}$ $\therefore$ $\frac{1000\ mm}{\text{Sec}} = \frac{L \cdot E}{L}$

$\therefore$ $\frac{W}{m^2} \cdot \frac{1000\ mm}{m} \cdot \frac{1\ m^3}{2.45 \times 10^9\ \text{Watt-sec}} = \frac{4.0816 \times 10^{-7}\ mm}{\text{Sec}}$

$\therefore$ $\boxed{\frac{1\ W}{m^2} = \frac{4.0816 \times 10^{-7}\ mm}{\text{Sec}}}$

$\boxed{\frac{1\ W}{m^2} = 1.606929 \times 10^{-8}\ \frac{\text{inches}}{\text{Sec}}}$

$\frac{1\ W}{m^2} = 5.7849 \times 10^{-5}\ \frac{\text{inches}}{\text{hour}}$

Leaf Water Potential and the Plant Stress Index

The purpose of ~~plant~~ leaf water potential (LWP) measurements is to ~~gauge~~ provide growers an ~~estimate of~~ indirect estimate of how much water is in the soil. The parameter that is being directly measured ~~by~~ with LWP is the transpiration rate ~~or flow of water~~ of the leaf (~~Black, 1983~~) (Rosenberg et al., 1983):

$$LE = \frac{LWP - Pa}{r_c + r_a} \quad (1)$$

LWP = leaf water potential

Pa = water potential of the air

r_c = resistance of a ~~leaf~~ crop to transpiration

r_a = aerodynamic resistance to water vapor flow.

LE = transpiration rate

~~The atmospheric resistance of a~~

The water potential of air is (Rosenberg et al., 1983):

$$P_a = \frac{R T_A}{V_W} \ln\left(\frac{RH}{}\right) \qquad (2)$$

R = gas constant
T_A = air temperature
V_W = volume occupied by 1 mole of water vapor
$\ln(RH)$ = natural logarithm of relative humidity

The transpiration rate of a leaf is also ~~proportional~~ equal to (Hatfield et al., 1983):

$$LE = R_N + G - \frac{\rho (T_L - T_A)}{r_a} \qquad (3)$$

R_N = net radiation
G = Soil heat flux, a function of ground cover
ρ = density of air * heat capacity of air
~~c_p = heat capacity of air~~
~~T_L~~ T_L = leaf temperature
T_A = air temperature

Substituting equations 2 and 3 into * equation 1:

$$(R_N + G) - d\frac{(T_L - \bar{T}_A)}{r_a} = \frac{\left[\lambda w P - \frac{R\bar{T}_A}{V_w} \ln(RH)\right]}{r_c + r_a}$$

Thus

$$(r_c + r_a)(R_N + G) - \frac{d(r_c + r_a)(T_L - \bar{T}_A)}{r_a} = \lambda w P - \frac{R\bar{T}_A}{V_w} \ln(RH) \quad (4)$$

Leaf water potential is therefore:

$$\lambda w P = (r_c + r_a)(R_N + G) - \frac{d(r_c + r_a)(T_L - \bar{T}_A)}{r_a} + \frac{R\bar{T}_A}{V_w} \ln(RH) \quad (5)$$

If r_a is assumed reasonably constant (a valid assumption if wind speed is greater than 5 mph), canopy resistance is assumed to be.

Equation 5 shows that leaf water potential depends on

- the stress status of the crop
- the sunlight intensity
- air temperature
- windspeed
- Relative humidity
- leaf temperature

In order to accurately use LWP for determining the stress status of ~~plants~~ leaves the following conditions must be met:

- ~~measure~~ LWP at consistent solar radiation levels. ~~Fluctuations of~~ Sunlight ~~or~~ should be measured to ~~correct~~ insure consistency
- leaf temperatures should be the same for each measurement or a correction for ~~leaf~~ varying leaf temperatures should be applied
- Air temperatures should be the same or a correction for varying air temperatures should be applied.
- corrections for relative humidity variation ~~is~~ necessary
- Correction for windspeed ~~or~~
- correction for changing ground cover.

Many growers use LWP measurements with a degree of satisfaction. Equation 5 shows that they simply may be in an environment which often has similar values of R_N, T_A, T_L and RH from day to day. As long as weather patterns truly are constant from day to day, uncorrected LWP values can be calibrated to indicate stress levels. Since even in places like Fresno California the weather changes, growers who use uncorrected LWP values can expect significant variability in the meaning of a given LWP value.

By contrast, the Scheduler is designed to respond directly to the transpiration rate of a canopy using equation 3. ~~As daylight intensity is reasonably constant and ground cover the Scheduler~~ The Scheduler index expresses equation 3 in terms of an index which ranges between

Equation 5 shows that LWP is a direct function of all the parameters composing the Scheduler stress index. The functional relationship between leaf water potential and the Scheduler index is:

$$LWP = f\left(R_N + (T_c - T_a) + VPD \right) \quad (6)$$

When leaf water potential measurements are corrected for environmental variability, there is a strong relationship between LWP and Scheduler readings (Idso et al., 1981, Reginato, 1983, Stark and Wright, 1985).

The correction factor used in these papers is based on equation 4 & ~~with as~~:

$$CWSI = LWP - f(VPD)$$

It is clear from a theoretical and empirical viewpoint that LWP are strongly related to plant stress index readings, and that LWP measurements ~~must~~ should be corrected for environmental variability before they are compared to Scheduler readings.

Rosenberg, N. J, B.L. Blad and S.B. Verma. 1983. Microclimate. The Biological Environment. pp. ~~240-241~~. 238-241

Hatfield, J.L., A. Perrier and R.D. Jackson. 1983. Estimation of Evapotranspiration at One time of day using Remotely sensed surface temperatures. Agricultural Water Management 7: 341-350.

Idso, S.B., R.J. Reginato, D.C. Reicosky and J.L. Hatfield. 1981. Determining Soil-Induced plant water potential depressions in alfalfa by means of infrared thermometry. Agronomy Journal 73: 826-830.

Reginato, R.J. 1983. Field Quantification of crop water stress. Transactions of the ASAE 26: 772-775 + 781.

Stark, J.C. and J.L. Wright. 1985. Relationship between foliage temperature and water stress in potatoes. American Potato Journal 62: 52-68.

Longwave Sky Radiation

$$R_{SKy} = \varepsilon_S \sigma T_{SKy}^4 \quad (W/m^2)$$

T_{SKy} = effective Sky radiative temperature (°K)

ε_S = Sky emissivity

Currently we do not have an IRT calibrated to measure the low Sky temperatures. Therefore, we can estimate R_{SKy} using ground based (1-2 meter heights) temperature and vapor pressure

$$\varepsilon_S = \varepsilon_A^{RVA} + C\left(1 - \varepsilon_A - 4\frac{\Delta T}{T_a}\right)$$

C = percent cloud cover/100

T_A = ground based air temp (°C)

Δ = difference between air temp and cloud base temp. ≈ 2

$$\varepsilon_A^{RVA} = 0.58(\rho_{va})^{1/7}$$

ρ_{va} = vapor density at 1-2 meters

$$\rho_{va} = e_a / (4.62 \times 10^{-4} \cdot (T_A + 273.1)) \quad (g/m^3)$$

$e_a = e_s'(RH)$ RH = Relative humidity

$$e_s' = 0.61078 \exp\left[(17.26939 * TA)/(T_A + 237.3)\right]$$

$$\therefore \boxed{R_{SKy} \approx \varepsilon_S \sigma T_A^4}$$

[The direct is positive (toward the crop)] ☆

Incoming Solar Radiation

I_s ~~R_s~~ is measured directly (W/m^2)
(incoming solar radiation)

$R_{SW} = R_{Top} + R_{Lower}$

Absorbed Solar = energy absorbed at top of canopy + " " " bottom " "

$$R_{SW} = I_{S_{SUN}}(1-\alpha_c) + \frac{I_S(\alpha_{soil})(1-\alpha_c)(1-P_g)}{I_{S_{SUN}}(1-\alpha_{soil})\alpha_c(1-P_g)}$$

α_c = ~~Re~~ crop Albedo $\approx$ 0.22

α_{soil} = soil Reflectivity $\approx$ 0.32

P_g = (Percent ground cover)/100

Longwave Soil (ground) Radiation

$$R_g = \varepsilon_g \sigma T_g^4$$

T_g = Average soil temperature below the crop (°K)
T_g can be measured with an IRT
$\varepsilon_g \cong 0.97$

Longwave crop Radiation (to ground & Sky)

$$R_c = 2\varepsilon_c \sigma T_c^4$$

$\varepsilon_c \cong 0.97$
T_c = canopy temperature (°K)

Convective Energy Transfer

$$E_c = 2h_c(T_A - T_c)$$

h_c = convective heat transfer coefficient $\left(\frac{W}{m^2\,{}^\circ C}\right)$

T_A = Air Temp. T_c = Crop Temp

$$h_c = \frac{\rho C_p}{r_v} \qquad \rho C_p = 1294.1 \ J/m^3\,{}^\circ C$$

r_v = Aerodynamic resistance

(1) To calculate R_V, first calculate The Reynolds Number:

$$Re = \frac{u\,d}{\nu}$$

u = windspeed (m/sec)

d = Leaf diameter (length) in direction of wind flow (m)

ν = kinematic viscosity of Air (m^2/sec)

$\nu = (132.7 + 0.9079 * T_A) \times 10^{-7}$

(2) Calculate The Grashof Number

$$Gr = \frac{a\,g\,d^3(T_c - T_a)}{\nu^3}$$

g = gravitational constant = 9.8 m/sec^2

a = coefficient of thermal expansion for air = $\frac{1}{273}$

IF $Re < 5 \times 10^5$ Then

$$r_V = 307 \left(\frac{d}{\mu}\right)^{1/2}$$

IF $Re > 5 \times 10^5$ and ~~$Gr < 0.5$~~ $Gr < 0.5$ Then

$$r_{V_1} = 0.7(307)\left(\frac{d}{\mu}\right)^{1/2} = r_{V_1}$$

IF $Re > 5 \times 10^5$ and $Gr > 0.5$ Then

$$r_{V_2} = 840 \left(\frac{d}{|(T_c - T_a)|}\right)^{1/4} = r_{V_2}$$

IF $Re > 5 \times 10^5$ and $0.5 < Gr < 1.5$ Then

~~r_V~~ $= \dfrac{r_{V_1} + r_{V_2}}{2}$ ~~$\dfrac{1}{\frac{1}{r_{V_1}} + \frac{1}{r_{V_2}}}$~~

$$r_V = \frac{r_{V_1} + r_{V_2}}{2}$$

Transpirational Energy Loss

$$T = 2L\left(\frac{\rho(T_c) - RH\,\rho(T_a)}{r_L + r_a}\right)$$

L = Latent heat of vaporization = $2340\ \frac{J}{g}$

$\rho(T_c)$ = density of saturated water at T_c (g/m^3)

$T_c = {}^\circ C$; $T_a = {}^\circ C$

RH = Relative humidity fraction = $\frac{RH\%}{100}$

$\rho(T_a)$ = density of saturated water at T_a (g/m^3)

$$\rho(T_c) = e_s(T_c) \Big/ \left[4.62 \times 10^{-4}(T_c + 273.1)\right]$$

$\rho(T_a)$ = same form

$$e_s = 0.61078 \exp\left[\left(\frac{17.26939 * T_a}{T + 237.3}\right)\right]$$

T is in $^\circ C$

$r_a = r_v$ (See pages 4-5)

r_L = internal leaf diffusion resistance $\left(\frac{sec}{m}\right)$

$$r_L = 100\left[2.098 - 3.723 R_N + 2.317 R_N^2\right]$$

$$R_N = 0.79(I_S)\left(\tfrac{1}{697.93}\right) = I_S/883.46$$

I_S = incoming solar radiation $(Watts/m^2)$

(Steady-State)

Model

Sky radiation; Solar Radiation; Ground Emitted Longwave; convection; radiant crop losses; transpiration; storage

$$R_{SKy} + R_{SUN} + R_g + E_c = R_c + T + \text{storage}$$

$R_{SKy} = f$ (% cloud cover, Rel. Hum., T_A)

$R_{SUN} = f$ (incoming solar, soil & crop reflectivities, % ground cover)

$R_g = f$ (soil surface temp)

$E_c = f(T_A, T_c,$ windspeed, crop-type)

$R_c = f(T_c)$

$T = f(T_a, T_c, RH,$ windspeed, crop-type, ϕI_s)

$\therefore$

$$\boxed{R_{SKy} + R_{SUN} + R_g = R_c + T - E_c} \quad (W/m^2)$$

The right hand terms all involve T_c, the left do not. Therefore, iterate to find T_c.

Constants

σ = Stefan-Boltzmann constant = $5.67 \times 10^{-8} \frac{W}{m^2 \cdot K}$

ρ = air density = 1.290 kg/m^3

c_p = air heat capacity = 1003.2 $J/Kg\ ^\circ C$

ρc_p = 1294.1 $J/m^3\ ^\circ C$

γ = psychrometric constant = $0.066 \frac{kPa}{^\circ C}$

ν = kinematic viscosity of Air

= $[132.6727 + 0.907878] \times 10^{-7}$ m^2/sec

L = latent heat of Vaporization = 2340 J/g

RELEAF.BRG

Relating Leaf Water Potential to Soil Water Potential

by Brown Gardner

The pressure ~~potential~~ measured by a pressure chamber is controlled by a) the soil water potential ~~and~~ b) the leaf osmotic potential and c) the vapor pressure deficit of the air.

$$LWP = f(SWP) + LOP + F(VPD)$$

where LWP = measured leaf water potential
f(SWP) = Soil water potential relationship
LOP = leaf osmotic potential
F(VPD) = vapor pressure deficit ~~relationship~~

but ~~LOP~~ the Van't Hoff relation says:

$$LOP = CRT$$

C = concentration of leaf solutes
R = gas constant
T = leaf water temperature = leaf temperature

Since ~~C and~~ R ~~is~~ constants and C ~~is approximately constant (depending on leaf age)~~ depends on leaf age:

$$LOP = f(T_L)$$

f = function of leaf age T_L = leaf temperature

Therefore, leaf water potential is a function of soil water potential, leaf age and leaf temperature:

$$LWP = f(SWP) + f(T_L) + f(VPD)$$

Thus, to use leaf water potential measurements to characterize soil moisture status, three conditions must be met:

1) leaf age must be accounted for or only leaves of the same age should be used. Leaf size can be a guide toward leaf age. or Can also leaves on the same nodes should be used as a guide to leaf age.

2) Leaf temperature should be the same for each sample. Ideally, an leaf temperature measuring device is needed to insure that only leaves with a pre-determined temperature are used.

3) Calibrate LWP to the VPD of the air.

If these criteria are met, it should be possible to accurately calibrate leaf water potential to soil water potential.

When these criteria are not met, the theoretical equations are not satisfied. ~~and~~ This ~~should~~ will lead a user to experience significant difficulty in the consistent interpretation of leaf water potential measurements.

Reference:

Milburn, J.A. 1979. Water Flow in Plants. ~~Longman~~ Published by The Longman Group, London.

Specific heat of water Calculations
-- Cloud effects

$$c_p = 4.185 \frac{J}{g\,^\circ C} = 4.185 \frac{J}{cm^3\,^\circ C} = 4.185 \times 10^6 \frac{J}{m^3\,^\circ C}$$

$$1\ Watt = 1 \frac{Joule}{Sec} \quad \therefore \quad 1\ Watt\text{-}Sec = 1\ J$$

$$\therefore c_p = 4.185 \times 10^6 \frac{Watt\text{-}Sec}{m^3\,^\circ C}$$

$$c_p = 4.185 \times 10^6 \frac{W}{m^2} \cdot \frac{Sec}{m\,^\circ C} \cdot \frac{1\ m}{1000 mm}$$

$$c_p = 4.185 \times 10^3 \frac{W}{m^2} \cdot \frac{Sec}{mm\,^\circ C}$$

Time to change ↓ Sec

mm °C ← magnitude of change

↑ depth of water

The energy (W/m^2) needed to raise the temperature of a plant canopy depends on the <u>effective depth of water</u> in the canopy.

When a cloud passes in front of the sun, the ~~leaf~~ canopy rapidly cools by a factor of approximately $1\,^\circ C / 100\ W/m^2$ incoming.

A change of in the incoming of $500\ W/m^2$ translates into a canopy temperature change of about $5\,^\circ C$.

A 5°C change in canopy temperature corresponds to a change of about 35 W/m² in the blackbody radiation of the canopy. (60 seconds is generally sufficient time.) This means that:

$$C_p \cdot \frac{60 \text{ seconds} \cdot 5^\circ C}{\chi} = 35 \text{ W/m}^2$$

where χ = effective depth of water in the canopy which is affected by fluctuations in R_N

$$\therefore \quad 4.185 \times 10^3 \frac{W}{m^2} \frac{sec}{mm^\circ C} \cdot \frac{1}{60 sec} \cdot 5^\circ C \cdot \chi(mm) = 35 \text{ W/m}^2$$

$\therefore$ Therefore $\chi(mm) = 0.1$ mm

$\therefore$

Technical Bulletin

Using the ST27

The ST27 Turf monitor can be used in several ~~modes~~ ways to produce valuable management information. ~~First~~

Management ~~Objectives~~ Goal

A golf course superintendent ~~manager~~ has ~~as~~ a primary goal of producing and maintaining greens ~~tees~~ and tees which are healthy, attractive and enjoyable to ~~play~~ play golf on. This goal is achieved by managing irrigation, fertilizer, and other cultural practices. The continuing question which the manager must ask is "how is the grass performing?" Experienced managers traditionally rely on visual indications to assist them in making their management decisions. Since the main ~~purpose~~ goal of a golf course superintendent is ~~the~~ to maintain

The visual appearance of the course, ~~is the judgement of the superintendent or that the visual appearance~~ visual assessments are essential. Many superintendents also attempt to judge the agronomic health of their turf by visual appearance. ~~this judg~~ ~~This can present~~ ~~Doing this creates the potential danger that problem areas will suddenly develop.~~ Unfortunately, the true health of turf is not always indicated by visual appearance. It is true that healthy greens look good. But it is also true that greens that look good today may be experiencing difficulty and may not look good tomorrow.

The difficulty of ~~so~~ accurately judging the health of an area, or the cause of a problem, solely on visual indications is the reason the ST-27 Turf Monitor was developed.

How the ST-27 Helps

Several studies have shown that when turf is healthy, ~~the~~ turf ~~surface~~ temperatures are very uniform, varying by no more than 3-4°F over an entire green. ~~As~~ When a green dries out ~~and, if~~ temperatures ~~may~~ may vary by 20°F or more. Yet in both situations, the greens look the same. If left too dry ~~long~~, a green will ~~be~~ develop hard spots and brown spots. The manager may believe he has "suddenly" developed some problems when in fact, ~~not~~ the green may have been signalling for many days that it was experiencing difficulty. With the ST-27, the manager ~~can be~~ has an early-warning of developing problems, instead of waiting for the problems to progress to the point when visual symptoms develop.

clerics
Trouble-Shooting
Management Suggestion
over-irrigation

The ST-27 also helps as a trouble shooting device. One superintendent who was "absolutely positive" that a problem on his 9th green was unrelated to soil moisture because that area was irrigated was ~~shocked~~ surprised to learn that the turf ~~was~~ in that spot was 19°F hotter than the rest of the green. After a careful inspection of the plumbing system, he discovered a piece of plastic blocking the line which supplied water to that section of green. This had gone unnoticed since he irrigates at night and since all the other sprinklers were operating normally. ~~On~~ After discovering a hot spot on his 12th green, he found that one of his assistants had turned the sprinkler off 2 days earlier to allow some golfers ~~players~~ to play through -- and had forgotten to turn them

back on. ~~The Obviously~~

The ST-27 provides answers to three major questions:

1. Are the temperatures of ~~the~~ my ~~the~~ turf surfaces uniform? If not, ~~the manager has a~~ there is a problem to solve. Uniform temperatures indicate ~~uniformity~~ optimum conditions ~~in other ways, such as irrig~~ areas which are water-logged become too hot also, encouraging the development of weed diseases.

2. Are sprinklers operating ~~that~~ the way I think they are? The temperature patterns are an indication of the effectiveness of a sprinkler pattern.

3. Are my assistants doing something with ~~my~~ the irrigation system I'm not aware of?

Management Suggestions

Variably Cloudy Periods

~~During~~ On days where the sun is frequently covered by clouds, the ST-27 can still be used effectively. On these type of days, the superintendent would probably ignore the stress index (unless measurements were ~~made~~ only under sunny conditions anyway). The bar-graph on the back of the gun is the primary analysis tool (when sunlight varies). ~~Wait for a~~ Simply wait for the sunlight to stabilize (the cloud has either moved away from the ~~sun~~ or moved in front of it). Then note the position of the bar graph as you aim the ST-27. Does it remain steady as you walk around the green, or does it jump around (indicating a hot spot)? Even under sunny conditions this is an easy to use technique. ~~which requires no further analysis. data collected~~

Sunny Periods

~~The Stress Index~~

The stress index is designed to operate between 11:00 a.m. and 4:00 p.m. under sunny conditions. Under these conditions, the following has been observed on bent-grass greens:

less than 0 - the best greens

~~0-4~~ 0-3 - the average good looking green

~~3-5~~ 3-5 visual changes begin occurring

above ~~4~~ 5 - severe stress, obvious visual signs ~~begin occurring~~

Because of differences in cutting ~~height~~ height, soil type, fertility practices, etc., it is possible to make the above scale shift by 1 or 2 units. We believe most ~~man~~ superintendents will want to keep the majority of their greens in the 0-1 region.

Example

The following represents a ~~hypothetical~~ scenario based on experience:

~~On~~ On a regular basis:

- measure the stress index and uniformity of your "best" tee or green.

- Compare the average stress index and uniformity ~~with~~ of tees and greens you're especially concerned about with "your best" area. Be sure to be as consistent as possible in sampling technique when making this comparison. Manage there other areas to duplicate the stress index and uniformity of your best area. Examine all your greens if time permits. On many courses, ~~all~~ 18 holes can be examined in an hour.

On sunny days:

- Take more time to examine the ~~temperature~~ stress patterns on selected tees and greens to identify the ~~extent of~~ effectiveness of irrigation applications or to evaluate the ~~scale~~ size of ~~or~~ a problem area. Visual

symptoms occur in the hardest hit areas first, but the affected area may be larger than indicated by the visual symptoms which initially appear.

Summary

The ST-27 monitors the temperature of turf and relates this temperature to "Normal Turf" via its unique index. It is the first tool to which allows a turf manager to easily determine the condition of his turf. It is easy to use, ~~provides rapid interpretat~~ providing the manager with an ability to create truly ~~uniformity in spite~~ uniform turf, both agronomically and visually.

Managing Turf with the SE 27

The following turf facts must be understood:

- Cool season and warm season grasses have different temperature tolerances.

- Optimum temperatures for root growth and shoot growth (leaves) are different. Shoot growth can proceed while root growth has stopped.

- Shoots that grow while the roots have stopped growing will deplete the carbohydrate reserves of the plant. This has important implications in the relationship between the ~~fertilizing~~ nutritional program of turf and its ability to survive in adverse conditions. The more precise the fertility program matches the physiological needs of the turf, the greater the ability of the turf to withstand heat stress if accompanied by proper irrigation.

necessarily

- Visual color is not an indication of turf health. Turf roots can be severely damaged and carbohydrate reserves exhausted, but still appear lush with proper fertilization and irrigation. Such a turf is "on the razor's edge" between looking great and collapsing and turning brown virtually overnight. The true health of turf can be judged only by examining it's root system.

- Surface temperatures can be a good indicator of the activity of a root system. To indicate turf root health, the cumulative effects of heat and moisture stress must be judged. It is the temperature pattern over time that is the most critical.

- If the temperature is too high for too long, on a single day, turf may ~~die or go dormant~~ develop problems. This is why syringing is often necessary, especially in areas that are hard to wet.

Comparison Between ~~Selected~~ Published Turf Baselines in the VPD range in which their data was collected

		VPD 1	2	3
Rossell (1988)	Kentucky Bluegrass			
Ram I	$\Delta T = 8.3 - 2.3\,VPD$ ($R^2 = 0.32$)	6.0	3.7	1.4
Sydsport	$\Delta T = 8.5 - 2.7\,VPD$ ($R^2 = 0.33$)	5.8	3.1	0.4
Baron	$\Delta T = 9.6 - 3.1\,VPD$ ($R^2 = 0.39$)	6.5	3.4	0.3
America	$\Delta T = 7.4 - 2.3\,VPD$ ($R^2 = 0.29$)	5.1	2.8	0.5
Midnight	$\Delta T = 8.1 - 2.6\,VPD$ ($R^2 = 0.33$)	5.5	2.9	0.3
		5.8 ± 0.5	3.2 ± 0.4	0.5 ± 0.3
	Perennial Ryegrass			
Prelude	$\Delta T = 7.8 - 2.7\,VPD$ ($R^2 = 0.27$)	5.1	2.4	0.6
Palmer	$\Delta T = 9.3 - 3.4\,VPD$ ($R^2 = 0.36$)	5.4	2.5	−0.9
Derby	$\Delta T = 8.6 - 2.8\,VPD$ ($R^2 = 0.26$)	5.8	3.0	0.2
Pennfine	$\Delta T = 7.3 - 2.3\,VPD$ ($R^2 = 0.19$)	5.0	2.7	0.4
Manhattan	$\Delta T = 9.3 - 3.2\,VPD$ ($R^2 = 0.36$)	6.1	2.9	−0.3
		5.5 ± 0.5	2.7 ± 0.3	0.0 ± 0.6
Carrow (1988)				
Tifway	$\Delta T = 5.74 - 1.25\,VPD$ ($R^2 = 0.25$)	4.5	3.2	1.9
Meyer Zoysiagrass	$\Delta T = 6.26 - 1.41\,VPD$ ($R^2 = 0.38$)	4.9	3.4	2.03
Common Centipede	$\Delta T = 4.69 - 0.86\,VPD$ ($R^2 = 0.16$)	3.8	2.9	2.11
		4.4 ± 0.6	3.2 ± 0.3	2.0 ± 0.1

Heat Stress

Absolute
Temp too high

Relative
too high

Moisture Stress

Absolute
O.K.

Index
too high

(Time: how many days > 95°F?)

Visual
Green/Brown & Optimal T_C, index high

Green/Brown & Optimal T_C, index low

Green/Brown & high T_C, index low

Green/Brown & high T_C, index high

~~Green~~

heat $
zone $
UARIA $
sun $
INDEX $

CLV 193-C

SHEET NO. _____ OF _____

FILE _____

SUBJECT _____

DATE _____

BY _____

Root growth

~~Bentgrass~~ Cool Season — stops at 90 °F

Biological death at 120 °F

Warm season stops at about 105

Biological death at ~~140~~ ~~130~~ ~~140~~ 135

Cool Season minimum = 40 °F

Warm Season minimum = 55 °F

cool season chlorophyll ↓ max at 75-85

optimum FC 75-85 F

bent. ⇒ Heat stressed at 95 °F

(darker green).

~~Heat - 3~~

~~Zone - 3~~

VARIA - 3

Std Sm - 2

Index = 4

Heat Zone	Sampling std	Sum std	Index

ST 27 Criteria

1. Stress must be indicated before the eye can see it, otherwise the ST 27 is useless. This means the instrument must say "stress" when the eyeball says its O.K.

2. Stress is defined as a reduction in ET level which will eventually cause a color change. The length of time for a given stress level to actually cause a color change depends on:

   - how long the current stress level has existed
   - fertility regime
   - grass mixture
   - cultural practices
   - severity of the weather
   - disease / insect problems

stress decision criteria

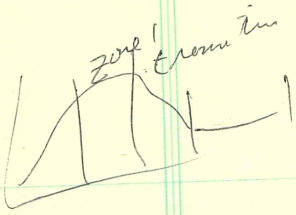
if $\overline{S.I.} > 4$, then => stress

if S.I < 4, then :

if Sun >

if Temp > 100 and cool season grass, then stress begins for sure
if Temp > 115 & warm season, then stress for sure

- Genetic differences among grasses allow for different tolerances to stress (length of time to turn color)



Stress Factor #1
Optimum Temperature)

$S1 = [T_c - T_o]$

$T_o =$ ~~80~~ ~~85~~ [60-75] cool season
[75-90] warm season

1) Is T_c < > T_o range:

~~#~~ ~~#2~~
Cool Season

60-75 = optimum
75-90 = transition, probably OK
90-125 = slow transition to brown

Stress # 2

How long at this T_c?

Has the temp been optimum for days or week?

#3

$T_c - T_a$

if $T_c - T_a$ is negative, transpiration / evaporation is adequate

if $T_c - T_a \geq 0$, then ~~condition~~ is ~~unknown~~ model

if $(T_c - T_a) > 23$ F then stress is guaranteed.

$(T_c - T_a) \geq 0$ ~~≤ 10~~, then highly ~~unknown~~

$(T_c - T_a) \geq 10$ ≤ 23 stress is likely

#4

(Std)

If STD $> 2°C$ $(4°F)$

Then stress is possible

#6

Sun Medic

heat / moisture

if Sun L 65, stress ~~is no~~ pressure should be relieved.

#5

elevation above danger point

1) cool season D.P. = 95 °F

2) warm season = 110 °F

$SS = (T_c - D.P.)$

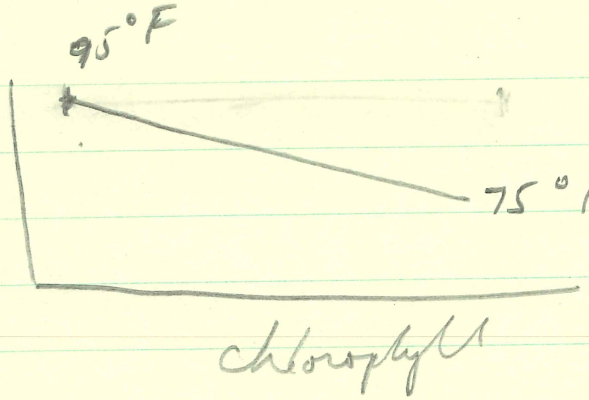
#6

If index is negative, then ignore.

Index must be positive

#6 Time

How long at a stress level?



- cool season Bentgrass
- Turf is greener at 95°F than at 75°F but has less chlorophyll.

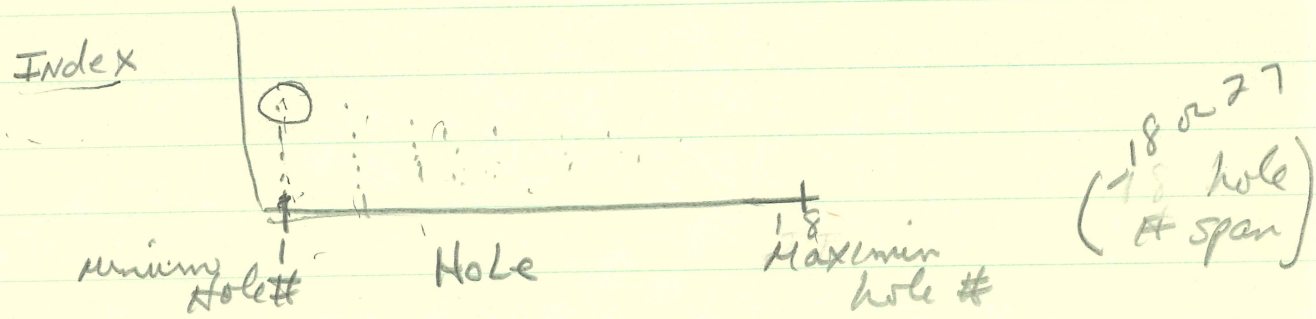
- Turfs appear darker green at soil temperatures which restrict root growth

Steve,

why don't we just delete the historical files out of the ST 27?

Also delete the automatic erasing of data at midnight

Then ~~on a daily~~ make 1 graph



put all 5 data points per hole on the 1 graph.

F
B
M

-Bronson

California ET_o (North → South)

County	City	JAN	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Santa Cruz	Watsonville	1.46	1.76	2.69	3.66	4.64	4.49	4.88	4.15	4.02	2.93	1.77	1.22
San Joaquin	Stockton	0.79	1.54	2.93	4.72	6.22	7.44	8.06	6.83	5.31	3.23	1.42	0.61
Merced	Merced	0.98	1.54	3.17	4.72	6.59	7.91	8.54	7.20	5.31	3.42	1.42	0.73
Napa	St. Helena	1.22	1.54	2.81	3.90	5.13	6.14	6.96	6.22	4.84	3.05	1.42	0.85
Sonoma	Santa Rosa	1.22	1.65	2.81	3.66	5.0	6.02	6.10	5.86	4.49	2.93	1.54	0.73
Madera	Madera	0.92	1.43	3.17	4.84	6.59	7.80	8.54	7.32	5.31	3.42	1.42	0.73
San Benito	Hollister	1.46	1.76	3.05	4.25	5.49	5.67	6.35	5.86	4.96	3.54	1.65	1.10
Monterey	Monterey	1.71	1.76	2.69	3.54	4.03	4.13	4.27	4.15	3.54	2.81	1.89	1.46
Kings	Hanford	0.85	1.54	3.42	4.96	6.59	7.68	8.30	7.20	5.43	3.42	1.42	0.73
Tulare	Visalia	0.98	1.76	3.42	5.43	6.96	8.15	8.42	7.20	5.67	3.78	1.65	0.85
Fresno	Fresno	0.85	1.65	3.30	4.84	6.71	7.80	8.42	7.08	5.20	3.17	1.42	0.61
Kern	Shafter	0.98	1.65	3.42	4.96	6.59	7.68	8.30	7.32	5.43	3.42	1.54	0.85
San Luis Obisbo	San Luis Obisbo	1.95	2.20	3.17	4.13	4.88	5.31	4.64	5.49	4.37	3.54	2.36	1.71
Santa Barbara	Santa Maria	1.83	2.20	3.17	4.02	5.00	5.08	5.13	5.13	4.49	3.54	2.36	1.71
Ventura	Oxnard	2.20	2.54	3.17	3.66	4.39	4.61	5.37	4.76	4.02	3.30	2.36	1.95
L.A.	Lancaster	2.14	2.98	4.64	5.91	8.54	9.69	10.98	9.76	7.32	4.64	2.78	1.71
L.A.	Long Beach	2.20	2.54	3.42	3.78	4.76	4.96	5.25	4.88	4.49	3.42	2.36	1.95
San Bernadino	Barstow	2.56	3.64	5.74	7.91	10.13	11.57	11.96	10.37	8.62	5.74	3.31	2.07
Orange	Santa Ana	2.20	2.65	3.66	4.49	4.64	5.43	6.22	6.10	4.72	3.66	2.48	1.95
Riverside	Palm Springs	1.95	2.87	4.88	7.20	8.30	8.50	11.59	8.30	7.20	5.86	2.72	1.71
	Riverside	2.07	2.87	4.03	4.13	6.10	7.09	7.93	7.57	6.14	4.15	2.60	1.95
San Diego	San Diego Warner Springs	2.20	2.54	3.30	3.43	4.39	4.02	4.64	4.64	3.90	3.30	2.24	1.95
Imperial	Brawley	2.81	3.75	5.86	8.03	10.37	11.46	11.72	10.01	8.39	6.22	3.54	2.07

Hyatt, Essex Room

5 Aug - 14 Sept - 1987

Clark Throssel

Range = 1 - 3 VPD

Kentucky Bluegrass

			R^2
1	Ram I	$\Delta T = 8.3 - 2.3$ VPD	0.32
2	Sydsport	$\Delta T = 8.5 - 2.7$ VPD	0.33
3	Baron	$\Delta T = 9.6 - 3.1$ VPD	0.39
4	America	$\Delta T = 7.4 - 2.3$ VPD	0.29
5	Midnight	$\Delta T = 8.1 - 2.6$ VPD	0.33

Perennial Ryegrass

			R^2
6	Prelude	$\Delta T = 7.8 - 2.7$ VPD	0.27
7	Palmer	$\Delta T = 9.3 - 3.4$ VPD	0.36
8	Derby	ΔT ~~8.6~~ $= 8.6 - 2.8$ VPD	0.26
9	Pennfine	$\Delta T = 7.3 - 2.3$ VPD	0.19
10	Manhattan II	$\Delta T = 9.3 - 3.2$ VPD	0.36

* Conclusions

1. Baselines vary among varieties within a species
2. At a VPD of < 2.5 KPa there is a considerable variability in canopy Temp
3. CWSI may have limited utility for irrigation scheduling at VPD of < 2.5 KPa

11 Standardbred Oil = 7.0 - 1.9 VPD

Carrow

Range = 1-3 VPD

12 Tifway ~~ΔT~~ $\Delta T = 5.74 - 1.25\ VPD$ $r = -.50$ $N = 37$

13 Meyer Zoysiagrass $\Delta T = 6.26 - 1.41\ VPD$ $r = -.55$ $N = 39$

14 Common Centipede $\Delta T = 4.69 - 0.86\ VPD$ $r = -0.40$ $N = 38$

Conclusion: $\Sigma (T_C - T_A) = SDD$ is better than CWSI in humid areas

R_N = 400 to 699 W/m²

Range = 7-5 VPD

Horst

Common Bermudagrass

15 1986 $\Delta T = 7.82 - 1.96$ VPD $r^2 = 0.54$ $N = 299$

16 1987 $\Delta T = 8.84 - 2.60$ VPD $r^2 = 0.53$ $N = 333$

Mowing height = 2.5 cm

Texoka Buffalograss

1986 $\Delta T = 9.27 - 2.11$ VPD $R^2 = 0.70$ $N = 299$

1987 $\Delta T = 9.40 - 2.74$ VPD $R^2 = 0.54$ $N = 305$

mowing ht = 5.0 cm

~~Raleigh~~ Raleigh St. Augustine

17 1986 $\Delta T = 7.36 - 2.03$ VPD $r^2 = 0.65$ $N = 299$

18 1987 $\Delta T = 6.26 - 2.19$ VPD $r^2 = 0.42$ $N = 313$

mowing ht = 5.0 cm

Falcon Tall Fescue - mowing ht = 5.0 cm

19 1986 $\Delta T = 6.35 - 1.97$ VPD $R^2 = 0.50$ $N = 299$

20 1987 $\Delta T = 6.50 - 2.50$ VPD $R^2 = 0.37$ $N = 327$

~~Conclusion~~ Results

1. Relationships of VPD vs $T_C - T_A$ varied as the meteorological conditions varied
2. Average R_N was less in 1987, Average VPD was less in 1987
3. VPD verses ΔT was more negative in 1987 (measurement Technique)
4. R^2 higher in 1986 then in 1987
5. Canopy Temp's more responsive to VPD in 1986 then in 1987.

Horst

Conclusions

1. Baseline relationships for ΔT should not be extrapolated beyond the region of data acquisition

2. Baseline relationships should not be extrapolated across different turfgrass species

3. Acquisition of data for baseline needs to be over the entire expected VPD range

4. Additional factors such as R_N, and windspeed need to be considered in the VPD x ΔT baseline for useful CWSI calculation.